FLOODPLAIN MAPPING AND MODELING FOR GERAY RIVER

By

ELIYAS BEZABEH TEGNIE

A Thesis submitted to

The Department of Civil Engineering, for partial fulfilment of the Requirements for the Degree of Masters of Science in Civil Engineering

(Hydraulic Engineering)

ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY

SEPTEMBER, 2018

DECLARATION

I hereby declare that this thesis entitled **"Floodplain Mapping and Modeling for Geray River"** was composed by myself, with the guidance of my advisor, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted, in whole or in part, for any other degree or procession.

Date: October 29, 2018

Name: Eliyas Bezabeh

Signature: _____________

APPROVAL PAGE

This MSc thesis entitled with ""**"Floodplain Mapping and Modeling for Geray River"**"" by **Mr Eliyas Bezabeh Tegnie** has been approved by the following examiners in partial fulfillment of the requirement for the degree of Master of Science in Civil Engineering (Hydraulics Engineering).

Date of Defense: **October 22, 2018**

Principal Advisor	Signature	Date

Members of the Examining board:

1.	External Examiner	Signature	Date
2.	Internal Examiner	Signature	Date
3.	Head, Civil Engineering Department	Signature	Date
4.	ERA PG Coordinator	Signature	Date
5.	Dean, College of Architecture and Civil Engineering Department	Signature	Date

Dedicate to my beloved parents

ABSTRACT

Flood is among the most devastating natural hazards in the world claiming lives and properties more than any other natural phenomena. The objective of this study was to analyse flood inundation area mapping and Modeling of Geray River Basin. This research involves the integration of Hydrologic Engineering centre-Hydrologic Modeling System and Hydrologic Engineering centre-River Analysis System with Geographic Information Systems to develop a regional model for floodplain determination, modeling analysis representation. The study describes the flood extent and depth in the area for different flow conditions derived from the historical flow data of the Geray River which is very important for floodplain mapping and modeling. The hydrologic model is calibrated using of Hydrologic Engineering centre-Hydrologic Modeling System for daily time series data for return periods of 2, 10, 25, 50 and 100 years. The value derived by the daily data of the of Hydrologic Engineering centre-Hydrologic Modeling System is compared with different frequency analysis methods. One dimensional hydraulic model Hydrologic Engineering centre-River Analysis System with HEC-GeoRAS interface in coordination with ArcGIS was applied for the analysis. The result of hydrologic model by Hydrologic Engineering centre-Hydrologic Modeling System shows a flow value of 109.1m^3/s, 214.9m^3/sec, 274.4m^3/sec, 318.4m^3/sec and 362.7m^3/sec for return periods of 2, 10, 25, 50 and 100 respectively. The result was compared with the frequency analysis using event flow values of the Geray River. According to the food map generated, the flooded area for the return periods 2, 10, 25, 50 and 100 Years are 0.87km^2, 1.08km^2, 1.16km^2, 1.23km^2 and 1.29km^2 respectively. The classification of flood depth area showed most of the flooding area had water depth less than 1.5m. On the other hand 83.33% of the flood inundated areas are covered by agricultural lands and the remaining 14.49% is covered by urban areas of Finote Selam and the rest 2.17% is covered by Agro-pastoral. And the flood damage estimated using depth-damage is 20.65 Km^2. Therefore, at most basic level, the best defence mechanism against flood in Geray catchment is to build dikes and levees on flood prone areas of the river reach.

***Key words**: HEC-HMS, HEC-RAS, TIN, DEM, Flood mapping and Modeling, Geray*

ACKNOWLEDGMENT

First and foremost, I would like to thank the Almighty God and his Holy mother Mary, for there care, support and endless love for my whole Life.

I am indebted to my respected advisor, Dr. Fitsum Tesfaye for his continuous guidance, advice and expedience from the proposal preparation to thesis finalization. His constructive comments, untiring help, guidance and practical suggestions inspired me to accomplish this work successfully. I would like to express my deepest gratitude to Mr. Niguse for his support in material and advises necessary for the work.

Finally, I offer my greatest and deepest appreciation to my beloved family and friends, for there prayer and continual follow up on my work and my daily life.

TABLE OF CONTENTS

DECLARATION .... **I**

APPROVAL PAGE .... **II**

ABSTRACT .... **IV**

ACKNOWLEDGMENT .... **V**

LIST OF TABLES .... **IX**

LIST OF FIGURES .... **X**

LIST OF ABBREVIATIONS .... **XIII**

CHAPTER ONE: INTRODUCTION **1**

1.1. Background 1

1.2. Statement of the Problems 2

1.3. Research Objectives 3

1.3.1. General Objective 3

1.3.2. Specific Objectives 3

1.4. Research Questions 3

1.5. Significance of the Research 3

CHAPTER TWO: LITERATURE REVIEW **4**

2.1. Historical Background of Flood Risk in Ethiopia 4

2.2. Hydraulic and Hydrology Flood Modeling 7

2.2.1. Hydrologic Model (HEC-HMS) 7

2.2.2. Hydraulic Model (HEC-RAS) 9

2.3. General HEC-GeoRAS or HEC-RAS Model Description 12

2.4. Flood Frequency Analysis 13

2.5. Flood Inundation Mapping 15

2.5.1. Water Surface TIN Generation 15

2.5.2. Floodplain Delineation 15

CHAPTER THREE: MATERIALS AND METHODS **17**

3.1. Description of the Study Area 17

3.1.1. Location 17

3.1.2. Topography 18

3.1.3. Climate 18

3.1.4. Land use and Land Cover 19
3.1.5. Soil Type 20
3.1.6. Geology 21
3.2. Data Collection and Analysis 23
3.2.1. Meteorological Data Availability and Processing 23
3.2.2. Estimating Missing Precipitation 23
3.2.3. Data Consistency and Homogeneity 24
3.2.4. Areal Precipitation 26
3.2.5. Flow data 27
3.2.6. Data filling and Consistency 27
3.2.7. Evapotranspiration 28
3.3. Developing Geometric Data 29
3.4. Development of DTM 30
3.5. TIN of the Study Area 31
3.6. Terrain Processing using Arc Hydro and HEC-GeoHMS 32
3.6.1. HEC-GeoHMS Geospatial Data Processing 32
3.6.2. Terrain Processing Using Arc-Hydro 33
3.7. Overview of Model Simulation 33
3.8. Hydrologic Modeling with HEC-HMS 33
3.8.1. Input data and Model Components 34
3.8.2. Modeling Approach 35
3.8.3. Model Calibration 38
3.8.4. Model Efficiency/Performance 39
3.8.5. Model Validation 40
3.8.6. Modeling by Frequency Storm Method 41
3.9. Flood Frequency Analysis 42
3.9.1. Normal Distribution 42
3.9.2. Lognormal Distribution 44
3.9.3. The Log-Pearson Type III Distribution 45
3.9.4. General Extreme Value Distribution 46
3.10. Hydraulic Modeling with HEC-RAS 47
3.10.1. Input Data and Model Components 47
3.10.2. Exporting to HEC-RAS 53

3.10.3. Entering Flow data and Boundary condition 54
3.10.4. Calibration of HEC-RAS for Manning's Roughness Coefficient 'n' 57
3.10.5. Exporting HEC-RAS Results and Post-RAS processing 58
3.11. Floodplain Delineation 58

CHAPTER FOUR: RESULTS AND DISCUSSIONS 59
4.1. Data Consistency and Homogeneity Results 59
4.2. Flow Data Results 60
4.3. Data Filling and Consistency 62
4.4. Terrain Processing Using Arc-Hydro Results 63
4.5. Model Calibration and Validation of HEC-HMS Results 66
4.6. Output of HEC-HMS by Frequency Storm 68
4.7. Flood Frequency Analysis Results 70
4.8. Calibration of HEC-RAS for Manning's Roughness Coefficient 'n' 71
4.9. HEC-RAS Output 72
4.10. Flooding on Jabi Tehnan Woreda 74
4.11. Flood Vulnerability and Damage Analysis 76
4.11.1. Flood Vulnerability Analysis 76
4.11.2. Flood Damage 77
4.12. Discussions 78

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS 80
5.1. Conclusion 80
5.2. Recommendations 81
5.2.1. Recommendation for Further Work 81
5.2.2. Engineering Mitigation Recommendation 82

REFERENCE 84

ANNEXES 88
Appendix A: Double Mass Curve of Stations near Finote Selam 88
Appendix B: Homogeneity Test Analysis 95
Appendix C: Estimated flow for Geray River 99
Appendix D: HEC-HMS outputs 100
Appendix E: HEC-RAS outputs 102

LIST OF TABLES

Table 1: Summary of Causes of Flooding, Flood Risk, and duration by Region 5

Table 2: Areas and Population Affected by Flood Disaster in the 2006 6

Table 3: List of selected gauging stations used for this study 24

Table 4: IDF table for the study area 41

Table 5: Manning’s Values for Different Land Uses (Chow, 1988) 54

Table 6: Correlation between Geray and other nearby Rivers using SPSS 62

Table 7: Correlation between Leza and other nearby rivers using Excel 62

Table 8: Catchment characteristic parameter extracted 65

Table 9: Optimized parameters of HEC-HMS for Geray catchment 66

Table 10: Determination of Peak Discharge Using HEC-HMS Frequency Method ... 68

Table 11: Comparison of flow values (frequency analysis and the HEC-HMS) 70

Table 12: Mean annual precipitation of stations 88

Table 13: Cumulative mean annual of the stations against Finote Selam 88

Table 14: Cumulative mean annual of the stations against Debre Markos 89

Table 15: Cumulative mean annual of the stations against Debre Work 90

Table 16: Cumulative mean annual of the stations against Felege Birhan 92

Table 17: Cumulative mean annual of the stations against Felege Birhan 93

Table 18: Finoteselam Station homogeneity data 95

Table 19: Debre Worke station homogeneity data 95

Table 20: Felege Birhan station homogeneity data 96

Table 21: Mehal Meda Station Homogeneity test data 97

Table 22: Homogeneity test to fill missing data 98

Table 23: Estimated monthly flow data for Geray River 99

Table 24: Profile Output table of HEC-RAS 109

LIST OF FIGURES

Figure 2-1: Flood in Geray watershed, 2006 4

Figure 3-1: Study area map 17

Figure 3-2: Topographic map of Geray Catchment 18

Figure 3-3: Average monthly rainfall (mm) and temperature (^{o}c) 19

Figure 3-4: Land cover, Land use of Jabi Tehnan Wored**a** 20

Figure 3-5: Major soil types of Jabi Tehnan Woreda 20

Figure 3-6: Geology of Jabi Tehnan Woreda 21

Figure 3-7: Flow chart of Floodplain Mapping 22

Figure 3-8: DMC of Finote Selam Vs. the four stations selected 25

Figure 3-9: TIN of the study area 32

Figure 3-10: Sub-basins of the Geray catchment 35

Figure 3-11: IDF Curve of Rainfall the Study area 41

Figure 3-12: Histogram of observed flow for Normal distribution 43

Figure 3-13: Histogram of observed flow for lognormal distribution 45

Figure 3-14: Histogram of observed flow for LP3 distribution 46

Figure 3-15: Histogram of observed flow for GEV distribution 47

Figure 3-16: Geray River Cross-section taken from Google earth 50

Figure 3-17: Geray River cross section in Google Earth 51

Figure 3-18: A digitized Geray River scheme with RAS layers 51

Figure 3-19: An underlying TIN and associated Geray River 52

Figure 3-20: A cross section views in HEC-RAS 53

Figure 3-21: Cross section of river at station 7200 of the Geray River 54

Figure 3-22: Calibration of manning's roughness coefficient using AHYDRA 57

Figure 3-23: Bounding polygon for the water surface TIN generation 58

Figure 4-1: DMC of four stations selected with high data consistency 59

Figure 4-2: Homogeneity Test for areal rainfall stations..60

Figure 4-3: Catchment similarity checking between Geray and Leza.........................61

Figure 4-4: Terrain processing for Geray sub basin using Arc hydro: 65

Figure 4-5: Calibration of HEC-HMS Output 67

Figure 4-6: Correlation between observed vs. simulated flow 67

Figure 4-7: Validation of HEC-HMS Output 68

Figure 4-8: 2 years flow hydrograph of Geray River 69

Figure 4-9: 100 years frequency streamflow hydrograph of Geray River...................69

Figure 4-10: Comparison of the flow values of the Geray River 70

Figure 4-11: 2D model for Manning's roughness calibration 71

Figure 4-12: 3D model of manning's roughness calibration 71

Figure 4-13: Cross section of River station 17576.52 for 2 years return period 72

Figure 4-14: General profile plot of the reach for 100 years storm 72

Figure 4-15: 3D view of the floodplain in HEC-RAS 100 years storm.......................73

Figure 4-16: RAS profile output table 74

Figure 4-17: Water surface TIN generated from bounding polygon 74

Figure 4-18: 100 years flood map and depth for the study area 75

Figure 4-19: 2 years flood map and depth for the study area 76

Figure 4-20: Vulnerability map of the study area...77

Figure 4-21: Flood damage of the study area 78

Figure A- 1: DMC of Finoteselam..89

Figure A- 2: DMC of Debre Markos 90

Figure A- 3: DMC of Debre Work 92

Figure A- 4: DMC of Felege Birhan...93

Figure A- 5: DMC of Mehal Meda...94

Figure A- 6: Homogeneity test graph 98

Figure A- 7: 10 year storm flow hydrograph 100

Figure A- 8: 25 year storm flow hydrograph 100

Figure A- 9: 50 year storm flow hydrograph 101

Figure A- 10: Water Surface Profile of 2 year storm 102

Figure A- 11: Water Surface Profile of 10 year storm 102

Figure A- 12: Water Surface Profile of 25 year storm 103

Figure A- 13: Water Surface Profile of 50 year storm 103

Figure A- 14: Water Surface Profile of 100 year storm 104

Figure A- 15: 3D view of 2 year flood 104

Figure A- 16: 3D view of 10 year flood 105

Figure A- 17: 3D view of 25 year flood 105

Figure A- 18: 3D view of 50 year flood 106

Figure A- 19: 3D view of 100 year flood 106

Figure A- 20: 10 year flood map and depth for the study area 107

Figure A- 21: 25 year flood map and depth for the study area 107

Figure A- 22: 50 year flood map and depth for the study area 108

LIST OF ABBREVIATIONS

2D: Two Dimensional

3D: Three Dimensional

amsl: Above Mean Sea Level

CDF: Cumulative density function

CFCA: Climatic and Atmospheric sciences

CLCF: Corn Land Cover Facility

CN: Curve Number

DEM: Digital Elevation Model

DMC: Double-Mass Curve

DPPA: Disaster Prevention and Preparedness Agency

DPPC: Disaster Prevention and Preparedness Commission

DTM = Digital Terrain Model

ERA = Ethiopian Road Authority

EU = European Union

GEV = General Extreme Value

GIS = Geographic Information System

GUI = Graphical user interface

HEC-DSS = Hydraulic Engineering Centre for Data Storage System

HEC-HMS = Hydraulic Engineering Centre for Hydrologic Modeling System

HEC-RAS = Hydraulic Engineering Centre for River Analysis System

I_a = Initial Abstraction

IDF = Intensity duration frequency

ITCZ = Intertropical Convergence Zone

LIDAR = Light Detection and Ranging

NMA = National Meteorological Agency

RF = Rainfall

RS = Remote Sensing

SCS = Soil Conservation Service

SPSS = Statistical Package for the social science

UH = Unit Hydrograph

USGS = United States Geological Survey

XS = Cross sections

CHAPTER ONE

INTRODUCTION

1.1. Background

Flood is among the most devastating natural hazards in the world claiming lives and properties more than any other natural phenomena. Flooding is one of the worst natural catastrophes, in terms of economic losses and number of deaths (Abaje, 2009).

A flood is an overflow of water that submerges land that is usually dry. The European Union (EU) Floods Directive defines a flood as a covering by water of land not normally covered by water. In the sense of "flowing water", the word may also be applied to the inflow of the tide. Flooding may occur as an overflow of water from water bodies, such as a river, lake, or ocean, in which the water overtops or breaks levees, resulting in some of that water escaping its usual boundaries, or it may occur due to an accumulation of rainwater on saturated ground in an aerial flood. While the size of a lake or other body of water will vary with seasonal changes in precipitation and snowmelt, these changes in size are unlikely to be considered significant (Aris, 2003).

Flood is a continuous natural and recurring event in floodplains of monsoon rainfall areas like Ethiopia, where over 80% of annual precipitation falls in the four wet months. An inundation map displays the spatial extent of probable flooding for different scenarios and can be present either in quantitative or qualitative ways (Sanyal & Lu, 2005).

The excess flows in water bodies can happen due to several factors, but seasonal heavy rainfall is the main cause of flooding in the Geray River. The problem of river flooding due to excess rainfall in the main rainy season (June, July, August, and September) in short time and the following high river discharge is a great concern in the Geray River, Ethiopia.

One purpose of flood mappings is to identify either flooding is going to occur in a specific location or not, on the time of flooding occurrence mitigation measures are taken to compensate the damage. Mitigation of flood disaster can be successful only when detailed knowledge is obtained about the expected frequency, character, and magnitude of hazardous events in an area as well as the vulnerability of the people, buildings, infrastructures and economic activities in a potential dangerous area (Van Western and Hofstee, 2000). One way to mitigate the effects of flooding is to ensure that all areas that are vulnerable are identified and adequate precautionary measures taken to ensure either or all of adequate preparedness, effective response, quick recovery and effective prevention. Before these could be done, information is required on important indices of flood risk identification which are elevation, slope orientation, proximity of built-up areas to drainages, network of drains, presence of buffers, extent of inundation, cultural practices as well as attitudes and perceptions (Abaje, 2009).

To get information on most of these, and identify areas that are vulnerable to flooding, reliable techniques of collecting and analysing geospatial information are required. In this regard, an integrated approach of Remote Sensing (RS), Geographic Information System (GIS) and HEC-RAS has proved to be the most effective (Jayaseelan, 2006).

In hydraulic flood modeling, availability of data in the required spatial and temporal resolution is vital. Topographic data is one of such data used as input in hydraulic flood modeling. Digital Elevation Model (DEM) and/or its derivative Triangular Irregular Network (TIN) is major source of topographic data for representing floodplain and river topography.

1.2. Statement of the Problems

Problems associated with flood are diverse and extremely complicated. Floods inundation build up property, endanger lives and prolonged high flood stages that delay highway traffic and cause damage to bridge abutment and other structure. To date, during high flow the Geray River flooded the vicinity of the area and causes loss of cultivated land and life. As its water carry heavy silt load and the river has a steep gradient, the river has a tendency to move sideways. In addition to this, the main bridge crossing the river, that connects Finote Selam and Jiga town, was damaged due to the flood. This causes loss of economy as result of both direct cost necessary to repair and indirect costs related to disruption of transportation facilities. Therefore, the purpose of this study is to develop flood mapping of the river and selection of river engineering mitigation measures.

1.3. Research Objectives

The following main and specific objectives have been formulated for this thesis work:

1.3.1. General Objective

The main objective of this study is to analyse the inundation area along the Geray River by integrating geomorphic, topographic and hydrological data using GIS and HEC-GeoRAS/ HEC-RAS Model.

1.3.2. Specific Objectives

1. To obtain flood levels for different return periods by flood frequency analysis.
2. To develop floodplain map and model of the river for different flow and conditions delineation of the flood model of the study area.
3. To perform flood damage vulnerability and analysis.

1.4. Research Questions

1. How does the river condition behave in high and low flow condition?
2. Does the flood occurring needs mitigation or bank scour counter measures?
3. Which areas are to be likely inundated by different return period?
4. What does the flood map describe (Indicate)?

1.5. Significance of the Research

Accurate and current floodplain maps can be the most valuable tools for avoiding severe social and economic losses from floods. Accurately updated floodplain maps also improve public safety. Early identification of flood-prone properties during emergencies allows public safety organizations to establish warning and evacuation priorities.

Flood inundation models are a major tool for mitigating the effects of flooding. They provide predictions of flood extent and depth that are used in the development of spatially accurate hazard maps. These allow the assessment of risk to life and property in the floodplain, and the prioritization of either the maintenance of existing flood defences or the construction of new ones.

CHAPTER TWO

LITERATURE REVIEW

2.1. Historical Background of Flood Risk in Ethiopia

Risk assessment of the flood prone areas in Ethiopia is not an easy task. There is a big shortage of adequate and reliable water and soil data. Moreover, the absence of stream flow data and the secrecy about survey reports of some major rivers, classified as "International Rivers", effectively block any thorough study of the topic (Alemu, 2007)

Figure 2-1: Flood in Geray watershed, 2006

However, there are some studies, particularly done by the then DPPC (now DPPA) and also by some other organizations and individuals, on flood risk in Ethiopia. In the past, there have been floods which have taken both human lives and destroyed properties. According to (DPPC, 1978) the following areas have been recognized as flood-prone areas.

- In Gondar Administrative Region immediately east of Lake Tana where River Ribb and Gumara enter the Lake.
- In Hararghe Administrative Region on the Wabe Shebelle River from Imi to Mustahil.

- In Illubabor Administrative Region on the Baro River from the town of Gambela to the border town of Jakao.
- In Wollo Administrative Region on the Awash River around Assayita.
- In Shewa Administrative Region around Tefki in the Teji Depression.

Another study conducted again by (DPPC, 1996), showed areas that suffer from flood risk at a national scale.

Table 1: Summary of Causes of Flooding, Flood Risk, and duration by Region

Source: (DPPC, Flood Risk Areas in Ethiopia, 1996)

Regions	Cause of flood	Flood Risk			Duration
		No. of affected population	No. of affected livestock	Property damaged in birr	
Tigray	Flash flooding	112	15	13835	1987
Afar	River flooding	445700	-	-	1985/87
Amhara	River flooding, Flash flooding	165363	2693	1504745	1985-88
Oromia	River flooding, Flash flooding	63359	359	9882811	1985-87
SNNP	Flash flooding, River flooding	252713	79781	4708683	1981/86/87
Gambela	River flooding	224828	-	-	1985/87
Fourteen	Flash flooding	10572	29	16400718	1986/87
Total		1162647	82877	32510792	

Although flood events are not new to Ethiopia, the country, in 2006 main rainy season, has been threatened by quite unprecedented flooding of abnormal magnitude and damage. Apparently, this is, for the large part, due to torrential or heavy rains falling for long days on the upstream highlands. The rains have caused most rivers to swell and overflow or breach their courses, submerging the surrounding ‘flat' fields or floodplains, which are mostly located in the outlying pastoralist regions of the country (Alemu, 2007).

As a result of the extended and widespread heavy rainfall as of the beginning of 2006 main rainy season, many areas have already experienced devastating damage. According to (DPPA, 2006), altogether some 635 people have died (364 in South Omo, 256 in Dire Dawa and 19 in various other parts of the country). Thousands have lost their property and means of livelihood. The soil in most areas is saturated and rivers are full.

In 2006, a total of some 524,400 people were vulnerable to flood disaster throughout the country. Out of this population, 199,900 people are actually affected by flood disaster in various areas (Table 2) (Alemu, 2007).

Table 2: Areas and Population Affected by Flood Disaster in the 2006

Source: (DPPA, 2006)

No.	Region	Vulnerable	Affected*
1	Afar	28000	4600
2	SNNP	106300	44000
3	Amhara	47100	47100
4	Oromia	61300	21900
5	Tigray	122300	2600
6	Dire Dawa	10400	10400
7	Somalia	87000	43200
8	Gambela	62000	26100
	Total	524400	199900

**The affected number of population includes 15 % contingency*

2.2. Hydraulic and Hydrology Flood Modeling

Flood model is one of the means to understand the behaviour of flood in a particular area. Model simulation can provide flood depth and extent. With the increase availability of the computing resources and the development of new models, flood hazard maps can be prepared at a high resolution with better accuracy for preparedness planning. Flood vulnerability map can be also prepared by integrating infrastructure and population data with the flood hazard maps. Flood models are the representation of hydraulic and hydrologic processes in the river channel and flood plain. Accurate representation of the actual processes is of paramount significance in predicting flood extent and depth, especially explaining the transient characteristics of river water flow in the model domain. Determining the variation of flow characteristics in the spatial and temporal resolution enables to design flood evacuation plan quite efficiently (Haile & Reintijs, 2005).

Flooding occurs due to too high stages in the river, which can be caused by at least three reasons that are: too high discharges, backing up of the water and increase in bed levels. Human influence is an important factor that many artificial changes in the river system may induce morphological changes and subsequent rising of the water or bed level.

Flood modeling will be helpful in understanding two things specifically the hydrologic modeling (how much water is there?) which determines for a given storm on a land escape, how much water will become a runoff and the hydraulic modeling (Where will it go?) takes the quantity of water and the shape of the land escape and stream channel and determines how deep and fast the water will be and what area will it cover. In this study the main study will be about the hydraulic modeling of flood using the hydrologic input data (Djokic, 2012).

2.2.1. Hydrologic Model (HEC-HMS)

HEC-HMS is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is designed to be applicable in a wide range of problems. This includes large river basin water supply and flood hydrology to small urban or natural watershed runoff. Hydrographs produced by the program can be used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, wetlands hydrology, and systems operation (David Ford, 2008).

Model components are used to simulate the hydrologic response in watershed. The primary model components are basin models, meteorological models and control specifications. There are also input data components. A simulation calculates the precipitation-runoff response in the basin model given input from the Metrologic model. The control specifications define the time period and time step of simulation run. Input data components, such as time-series data, paired data and gridded data are often required as parameter or boundary conditions in basin and Metrologic models (David Ford, 2008).

2.2.1.1. Basin Model

The basin model contains data, which represents the physical system of the study area in consideration. The descriptive data is entered by the user or imported from GIS and can be edited. Such data includes specification of the hydrologic elements of which the basin model is comprised, information on how the hydrologic elements are connected, and values of parameters for the hydrologic elements. The capability to configure a basin model by “dragging-and-dropping” icons on a schematic display is provided. The element data can be edited with single element or global editors. A basin model consists of hydrologic elements, of which there are seven types: sub basin, routing reach, junction, reservoir, diversion, source, and sink. The development of a basin model requires the specification of such elements and data that controls their 'behaviour’ (David Ford, 2008).

Geray catchment has three sub-basins with the gauge located near Finote Selam. The basin map is extracted from the GIS with the coordinate of the gauging station. The sub-basins are also provided with one reach each and a common point junction.

The Basin Model uses the following spatial data: River Reach Files for Stream network with junctions and diversions, Stream parameters (Muskingum K and X), Sub-basin data components: Loss parameters, routing parameters, and base flow values and computation methods and downstream points

2.2.1.2. Precipitation Model

The Precipitation Model is a set of information required to define historical or hypothetical precipitation to be used in conjunction with a basin model. Several options exist for specifying historical precipitation:

A. Utilize cell based precipitation as required for the Modified Clark method;
B. Import previously determined spatially-averaged precipitation;
C. Specify gages and their locations and weights and locations of index nodes, to be used in an automated inverse distance-weighting;
D. Specify gages and associated weights (e.g., from Thiessen polygons).

Even though the HEC-HMS can use any time step time series data, the case for flood modeling is effective with hourly data. The Finote Selam area rain gauge stations are not provided with hourly measurements, therefore daily measurements was undertaken (David Ford, 2008).

2.2.1.3. Control Specifications

The Control Specifications define time-related information for a simulation, including the starting and ending dates and the time interval for computations. The function of control specifications is to set the starting and ending dates and times and time (computation) interval. The time step for HEC-HMS model calibration for the catchment is divided into different time steps as for calibration, simulation and verification (David Ford, 2008).

2.2.2. Hydraulic Model (HEC-RAS)

HEC-RAS is an integrated system of software, designed for interactive use in a multi-tasking environment. The system is comprised of a graphical user interface (GUI), separate analysis components, data storage and management capabilities, graphics and reporting facilities (Gary, 2016).

The floodplain visualization was carried out using one-dimensional numerical model HEC-RAS. HEC-GeoRAS, an ArcGIS extension, is used as the interface between HEC-RAS and GIS for pre-processing and post-processing of the data in GIS. The availability of floodplain survey data for the new and the old alignment of the river, the pre and post processing using the HEC-GeoRAS is not complicated (Gary, 2016).

The geometric data of the floodplain and River is obtained from the digital elevation model (DEM) for the points where the plain showing less number of cross-sections. Water surface profiles, along the river reach under study, for floods of various return periods were computed with sub critical flow simulation. These profiles were exported to GIS and water surface Triangular Irregular Network (TIN) was generated. An intersection of the terrain TIN and water surface TIN results in flood map (Gary, 2016).

2.2.2.1. HEC-RAS Parameters

HEC-RAS uses a number of input parameters for hydraulic analysis of the stream channel geometry and water flow. These parameters are used to establish a series of cross-sections along the stream. In each cross-section, the locations of the stream banks are identified and used to divide into segments of left floodway (overbank), main channel, and right floodway. HEC-RAS subdivides the cross sections in this manner, because of differences in hydraulic parameters. For example, the wetted perimeter in the floodway is much higher than in the main channel. Thus, friction forces between the water and channel bed have a greater influence in flow resistance in the floodway, leading to lower values of the Manning coefficient (Gary, 2016).

As a result, the flow velocity and conveyance are substantially higher in the main channel than in the floodway showing higher values of manning's resistance coefficient. At each cross-section, HEC-RAS uses several input parameters to describe shape, elevation, and relative location along the stream:

- River station (cross-section) number
- Lateral and elevation coordinates for each (dry, un-flooded) terrain point
- Left and right bank station locations
- Reach lengths between the left floodway, stream centreline, and right floodway of adjacent cross-sections (The three reach lengths represent the average flow path through each segment of the cross-section pair. As such, the three reach lengths between adjacent cross-sections may differ in magnitude due to bends in the stream.)
- Manning's roughness coefficients (may vary horizontally or vertically)
- Channel contraction and expansion coefficients

- Geometric description of any hydraulic structures, such as bridges, culverts, and weirs

2.2.2.2. Data requirements for the HEC-RAS model

A. Geometry Data

Cross section data represent the geometric boundary of the stream. Cross sections are located at relatively short intervals along the stream to characterize the flow carrying capacity of the stream and its adjacent floodplain. Even though it is not a must, it is advisable to take cross section at constant interval. Cross sections are required at representative locations throughout the stream and at locations where changes occur in discharge, slope, shape, roughness; at locations where levees begin and end; and at hydraulic structures (bridges, culverts, and weirs) (Gary, 2016).

The required information for a cross section consists of: the river, reach and river station identifiers; a description; X & Y coordinates (station and elevation points); downstream reach lengths; Manning's roughness coefficients; main channel bank stations; and contraction and expansion coefficients (Gary, 2016).

B. Flow Data

Once the geometric data is entered, the necessary flow data can be entered. Steady Flow Data consist of: the number of profiles to be computed; the flow data; and the river system boundary conditions. At least one flow must be entered for every reach within the system. Additionally, flow can be changed at any location within the river system. Flow values must be entered for all profiles. Flow values can be imported directly from the HEC-HMS run for different hypothetical design storms or entered manually from the model run results. The flow data for the Geray River is assumed the one that is simulated by the HEC-HMS. Because of sedimentation and frequent washing of the River channel due to nature of the topography, the observed flow is assumed less (Gary, 2016).

C. Plan Data

Usually the first step in performing a simulation is to put together a Plan. The Plan defines which geometry and flow data are to be used, as well as provide a description and short identifier for the run. If the geometry and flow data do not exist, then this action is performed after their creation. Also included in the plan information are the selected flow regime and the simulation options (Gary, 2016).

2.3. General HEC-GeoRAS or HEC-RAS Model Description

The Hydrologic Engineering Centres' Geographical River Analysis System (HEC-GeoRAS) or HEC-RAS has been developed by US Army Corps of Engineers Hydrologic Engineering Centre and it is a free downloadable with other supportive documents about how to use the model for flooded area mapping. The HEC-GeoRAS is a GIS extension with a set of procedures, tools, and utilities for the preparation of river geometry GIS data to import into HEC-RAS and it is used to generate the final inundation map. The input data required for the River geometry preparation using the HEC-GeoRAS model are Triangular Irregular Network (TIN), DEM, and land use. The river geometry file and stream flow data are the input files for HEC-RAS to generate the water surface level along the River. The HEC-GeoRAS or HEC-RAS has been used worldwide for inundation mapping (Getahun YS, 2015).

HEC-GeoRAS is a data management interface between ArcGIS and HEC-RAS. This tool provides or creates the river geometric file to be analysed in HEC-RAS model. The river stream centreline, bank lines, flow path centrelines, and cross sections cut lines should be digitized from a previous river file, aerial photographs, or topographical datasets using HEC-GeoRAS interface. The river reach (river segment between junctions), cross-section and other related data are stored in the geo database file of HEC-GeoRAS (Botes & Smith, 2010). The river and cross-section data layers are created with predefined attribute tables that are manually populated in the case of the river and reach names, while all other attributes are automatically calculated by the HEC-GeoRAS (Botes & Smith, 2010).The interface extracts the geometric data in an .xml format that is imported into HEC-RAS. The results of the HEC-RAS model simulation will be entered into a GIS environment and further analyses will be performed using HEC-GeoRAS tool. The GIS data exchanged between HEC-RAS and ArcGIS are in '.sdf' file format (Parviz & Mohammad, 2013).

It is possible to edit the exported GIS geometric data in the HEC-RAS model using the HEC-RAS editor tools. The HEC-RAS consists of a number of editors tools to deal with different functions in the modeling process. For this study only the geometric, steady flow data, cross-section, and steady flow simulation editors will be used. The .xml file exported from the HEC-GeoRAS is imported into the Geometric Editor, which is a Graphical User Interface (GUI) that is used to manage the geographic data (Brunner, 2013). In this editor, the Manning friction values are entered for the cross-sections of each reach. The stream flow data is entered into the steady flow data editor. This editor extracts the river and data for the reaches from the geometric editor (Brunner, 2013). To compute the water surface level, the model needs to know the starting water level at the start and end of reaches that are not connected and at junctions to other reaches (boundary conditions). For a steady flow analysis, four types of boundary conditions are available, namely known water surface level, critical depth, normal depth, and rating curve. The steady flow water surface profiles module is used for calculating water surface profiles for steady, gradually varying flow using supercritical, subcritical and mixed flow regimes. The model solves an energy loss equation between two cross-sections using friction and contract/expansion coefficients. The output data of HEC-RAS model are water surface profile variations for different flow rates with varied recurrence intervals in desired lengths of the river, current velocity values, normal depth, critical depth, and hydraulic properties and parameters in the river (Brunner, 2013) (Botes & Smith, 2010).

The HEC-GeoRAS assists the ArcGIS in providing pre-processing, direct support, and post-processing functionality before and after the hydraulic analysis. For pre-processing, both HEC-GeoRAS and ArcGIS packages should pre-process data, but HEC-GeoRAS provides the extra capability to capture the geometric data according to the HEC-RAS format required for the hydraulic modeling. The HEC-GeoRAS exports and imports the spatial data to different formats between ArcGIS and HEC-RAS by using a data exchange format called a RAS GIS File (Els, 2011).

2.4. Flood Frequency Analysis

Flood frequency studies relate the magnitude of discharge, stage, or volume to the probability of occurrence or exceedance. The resulting flood-frequency functions provide information required for:

- Evaluating the economic benefits of flood-damage reduction projects.
- Sizing and designing water-control measures if a target exceedance level or reliability is specified.
- Establishing reservoir operation criteria and reporting performance success.
- Establishing floodplain management regulations.
- Developing requirements for regulating local land use. (David Ford, 2008)

Flood frequency analysis is a technique used by hydrologists to predict flow values corresponding to specific return periods or probabilities along a river. The application of statistical frequency curves to floods was first introduced by Gumbel. Using annual peak flow data that is available for a number of years, flood frequency analysis is used to calculate statistical information such as mean, standard deviation and skewness which is further used to create frequency distribution graphs. The best frequency distribution is chosen from the existing statistical distributions such as Gumbel, Normal, Lognormal, Exponential, Weibull, Pearson and Log-Pearson. After choosing the probability distribution that best fits the annual maxima data, flood frequency curves are plotted. These graphs are then used to estimate the design flow values corresponding to specific return periods which can be used for hydrologic planning purposes. Flood frequency plays a vital role in providing estimates of recurrence of floods which is used in designing structures such as dams, bridges, culverts, levees, highways, sewage disposal plants, waterworks and industrial buildings . In order to evaluate the optimum design specification for hydraulic structures, and to prevent over-designing or under designing, it is imperative to apply statistical tools to create flood frequency estimates. These estimates are useful in providing a measurement parameter to analyse the damage corresponding to specific flows during floods. Along with hydraulic design, flood frequency estimates are also useful in flood insurance and flood zoning activities. Accurate estimation of flood frequency not only helps engineers in designing safe structures but also in protection against economic losses due to maintenance of structures.

Knowledge of the magnitude and probable frequency of recurrence of floods is necessary to the proper design and location of structures such as dams, bridges, culverts, levees, highways, waterworks, sewage disposal plants, and industrial buildings. Knowledge of flood frequency is also necessary to flood insurance and flood zoning, activities which are now considered on a broad scale (Dalrymple, 1960).

In order to understand how flood frequency analysis works, it is essential to understand the concept of return period. The theoretical definition of return period is the inverse of the probability that an event will be exceeded in a given year. In general, return period, which is also referred as recurrence interval, provides an estimate of the likelihood of any event in one year. These events include natural disasters such as floods or earthquakes. Return periods are used to convey the risks of rate events more effectively that simply stating the probabilities.

The flood frequency curve is used to relate flood discharge values to return periods to provide an estimate of the intensity of a flood event. The discharges are plotted against return periods using either a linear or a logarithmic scale. In order to provide an estimate of return period for a given discharge or vice versa, the observed data is fitted with a theoretical distribution using a cumulative density function (CDF). This helps the users in analysing the flood frequency curve.

2.5. Flood Inundation Mapping

Inundation mapping is performed using the water surface elevations on the cross-sectional cut lines feature class and is limited to bounding polygon features. These two feature classes must be created prior to performing the inundation mapping. Floodplain delineation also requires the digital terrain model (Ackerman, 2009).

2.5.1. Water Surface TIN Generation

The first step in floodplain delineation process is to create a water surface TIN from the water surface elevations attached to each cross-section. A water surface TIN for each profile will be created irrespective of the terrain model. The ArcGIS triangulation method will create the surface using cross sectional cut lines as hard breaklines with constant elevation (Ackerman, 2009).

2.5.2. Floodplain Delineation

Floodplain delineation is performed using the water surface TIN and terrain model to calculate the floodplain boundary and inundation depths. The floodplain delineation process using HEC-GeoRAS is an iterative process that should be used to refine the hydraulic model in HEC-RAS (Ackerman, 2009).

The floodplain delineation method rasterizes the water surface TIN using the rasterization cell size and compares it to the DTM/GRID. The floodplain is calculated where the water surface grid is higher than the terrain grid. The bounding polygon is used to limit the floodplain only to the area modelled in HEC-RAS (Ackerman, 2009).

The DEM (digital elevation model) was processed to create the TIN (triangular irregular network). After that, the river cross-sections, stream centreline, stream bank lines, flow lines, and other river geometry information will be extracted from the TIN for the HEC-GeoRAS model. At the same time, the land use will be processed to get the Manning's n value for the individual cross-sections. After the RAS geometry data preparation, the HEC-GeoRAS model will be used to generate the RAS GIS import file (final river geometry file) that can be used as input for HEC-RAS (Getahun YS, 2015).

Checking the cross-section; editing the river geometry, and making final correction of the river geometry file in the HEC-RAS model. After the compilation of the final river geometry file, the 5% highest flows will be imported from gauging stations in different return periods and the HEC-RAS generated water level for different return periods. The water surface level for each return period will be exported in HEC-GeoRAS for final inundation area mapping along the river (Getahun YS, 2015).

CHAPTER THREE

MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

Geray River is located in North-Western part of Ethiopia, as one of Tributary River to the Abay River. Geray River is exactly located in Jabi Tehnan Woreda which is one of the woredas in the Amhara Region of Ethiopia at Aerial location between 10°39' and 10° 49' N latitude and 37° 10' E and 37°17' E longitude.

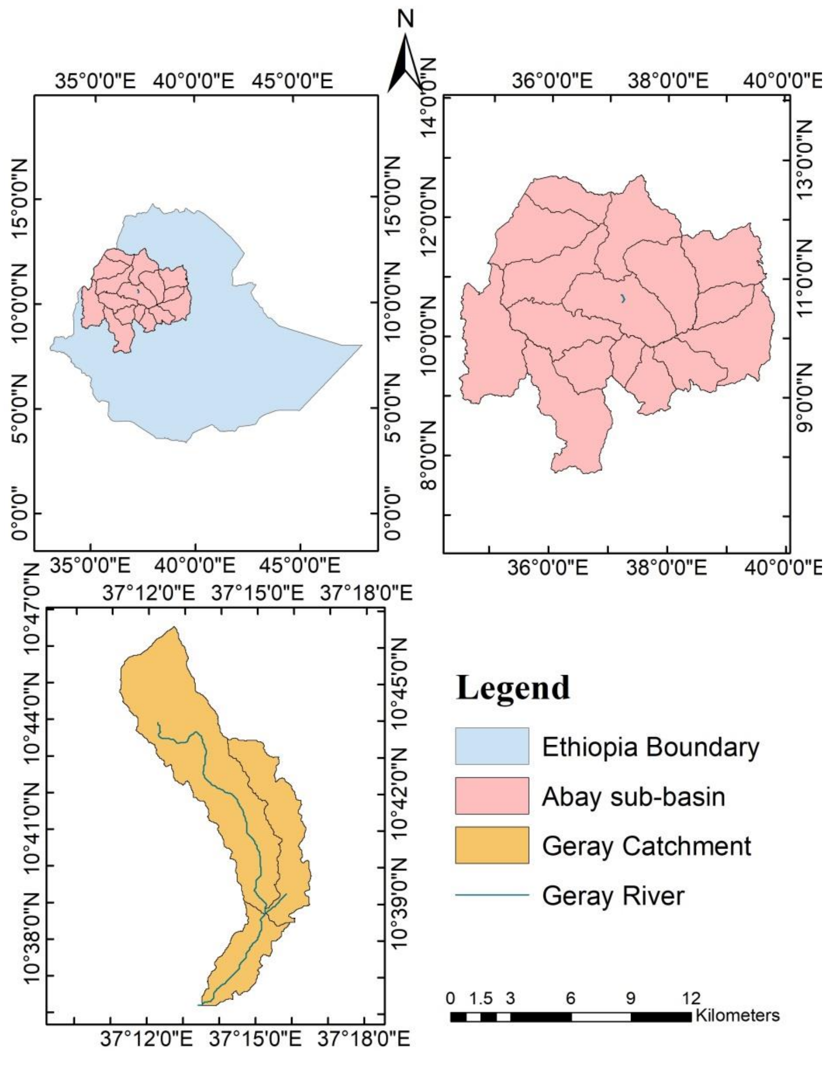


Figure 3-1: Study area map

Source: Extracted from ASTER

3.1.2. Topography

The elevation of the catchment ranges from 1400 to 2600 m amsl. The slope of the floodplain approximates 0.032% which is quite mild. The upstream of the catchment is highly mountainous while it is very flat at its lower reaches.

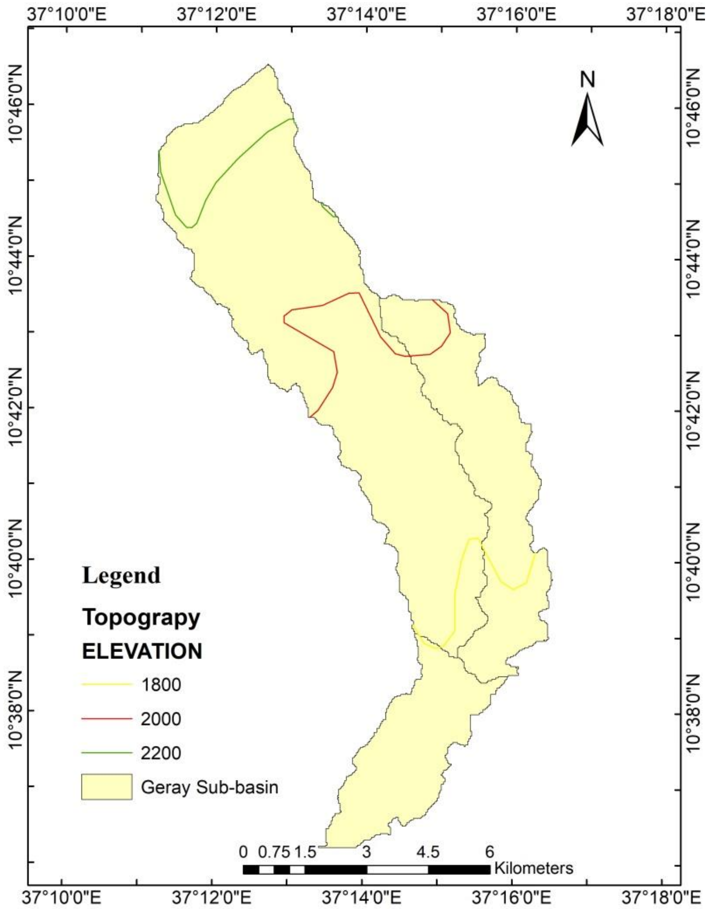


Figure 3-2: Topographic map of Geray Catchment

3.1.3. Climate

Ethiopia has three distinct seasons, each with differing precipitation totals. The Belg, approximately defined by March to the end of May, is considered the minor rainy season for most of the river basins, and is generated by weather systems that originate over the Indian Ocean (Seleshi & Zanke, 2004).

Ecologically, the Jabi Tehnan Woreda is located in a tropical at rainy climatic zone (locally called: Woina Dega) which receives the highest amount of annual rainfall during summer season (June, July, August and September). There is no meteorological station within the watershed and based on long term climatic data from nearby meteorological station (Finote Selam, Debre Markos, Debre Work and Felge Birhan), the study area has 29.5^{o}C and 12.9^{o}C of average maximum and minimum temperatures, respectively and meanwhile the mean monthly rainfall of the main rainy season is 246.92 mm. The highest mean monthly temperature was recorded in March and the lowest in December and January (Checko, 2014).

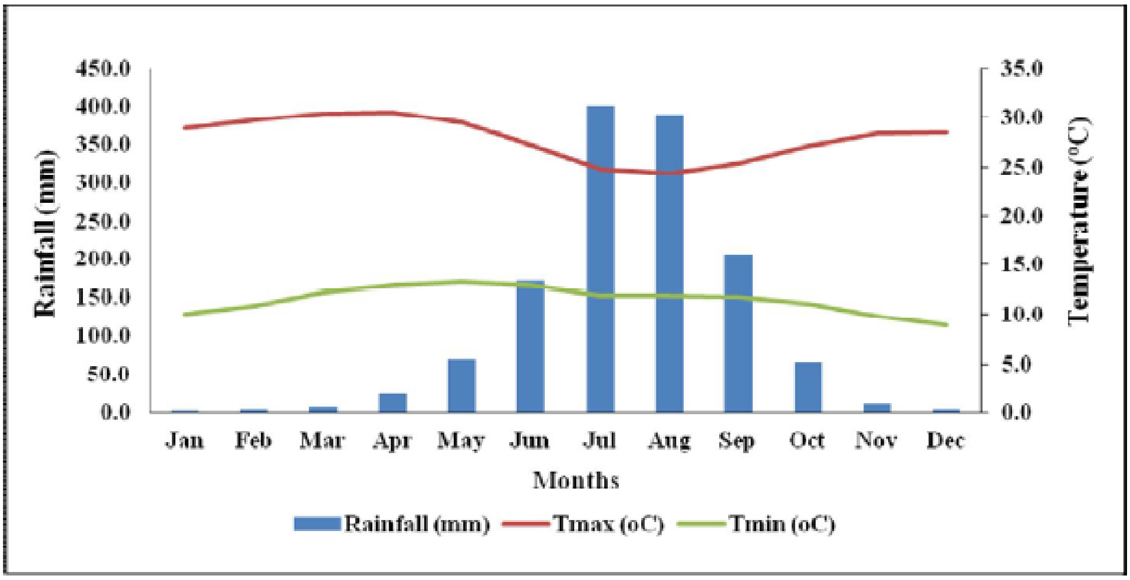


Figure 3-3: Average monthly rainfall (mm) and temperature (^{o}c)

(1986−2013) (Source: National Meteorology Agency)

3.1.4. Land use and Land Cover

Ecological infrastructure such as vegetation cover type, soil characteristics, plant, and settlement densities affects the infiltration characteristics and influences the storage coefficient and runoff behaviour. Land use of the flood plain is mainly dominated by Agricultural land and Agro-Pastoral followed by state farm, sylvo-pastoral and urban. Most of the study area land cover is characterized by Dominantly Cultivated and Moderately Cultivated lands as most of the area is rural.

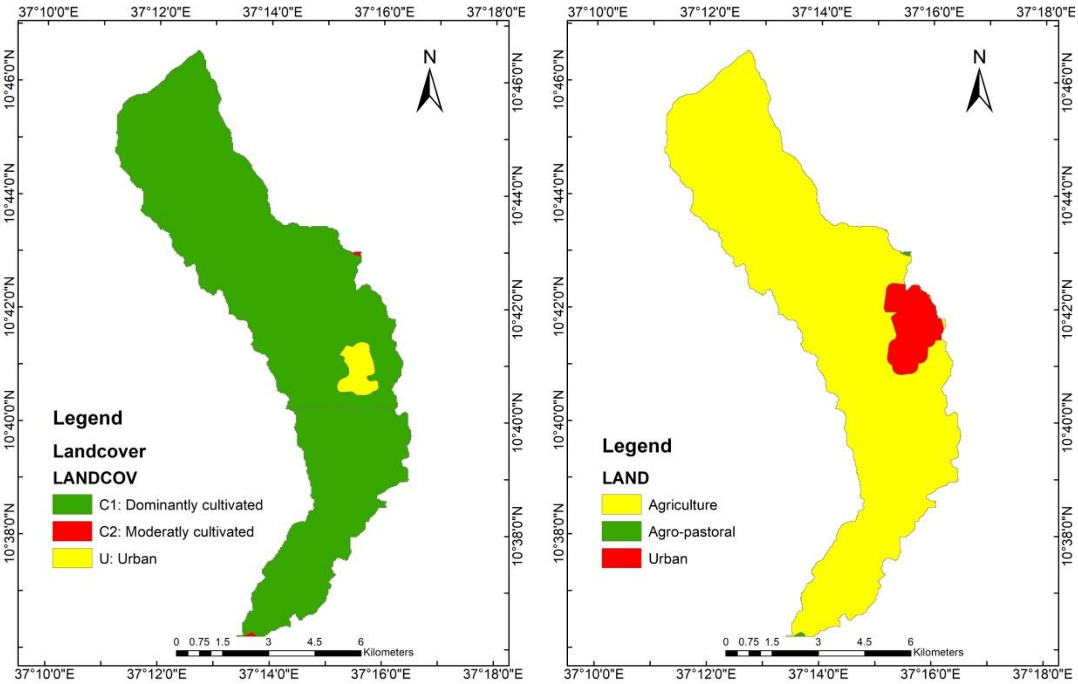


Figure 3-4: Land cover, Land use of Jabi Tehnan Wored**a**

3.1.5. Soil Type

The catchment is dominated by Haplic Alisols and Haplic Nitsols. The two soil types cover almost 60 % of the area. Eutric Fluvisols and Lithic Leptosols are another type of soils which dominated the catchment.

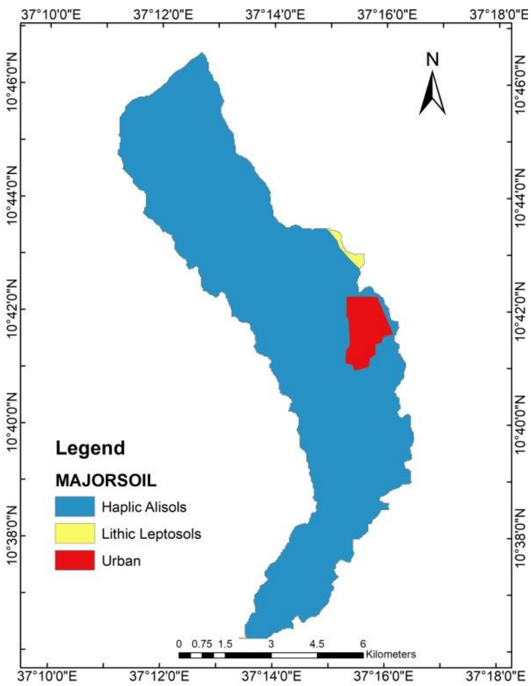


Figure 3-5: Major soil types of Jabi Tehnan Woreda

3.1.6. Geology

The geology is dominated by the Precambrian basement rock underlying Mesozoic marine sediments and Tertiary flood basalt. An integral part of the present day geology of the study area fall into transitional basalts (rocks) forming shield in the tertiary highland volcanoes with minor trachyte and Ashenge formation deeply weathered alkaline and transitional basalt flows. It also falls into the late Palaeozoic to early tertiary sediment and Cainozoic volcanic and associated sedimentary rocks.

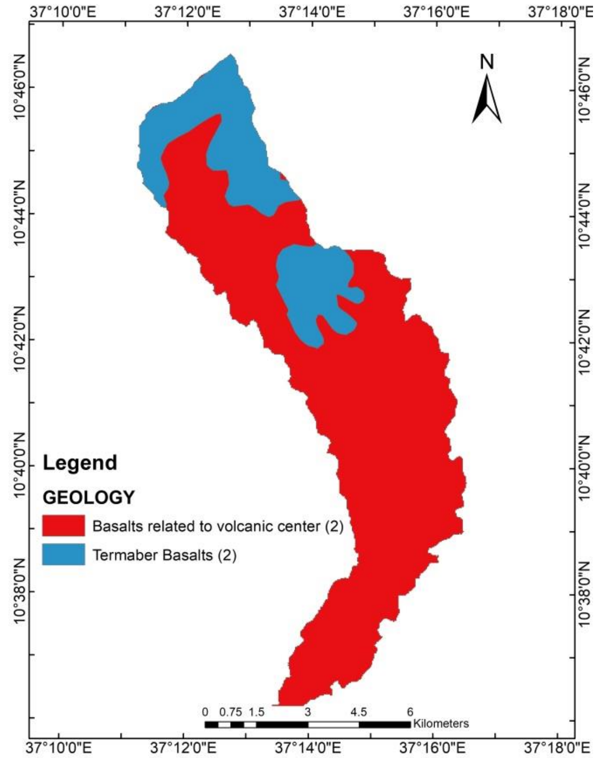


Figure 3-6: Geology of Jabi Tehnan Woreda

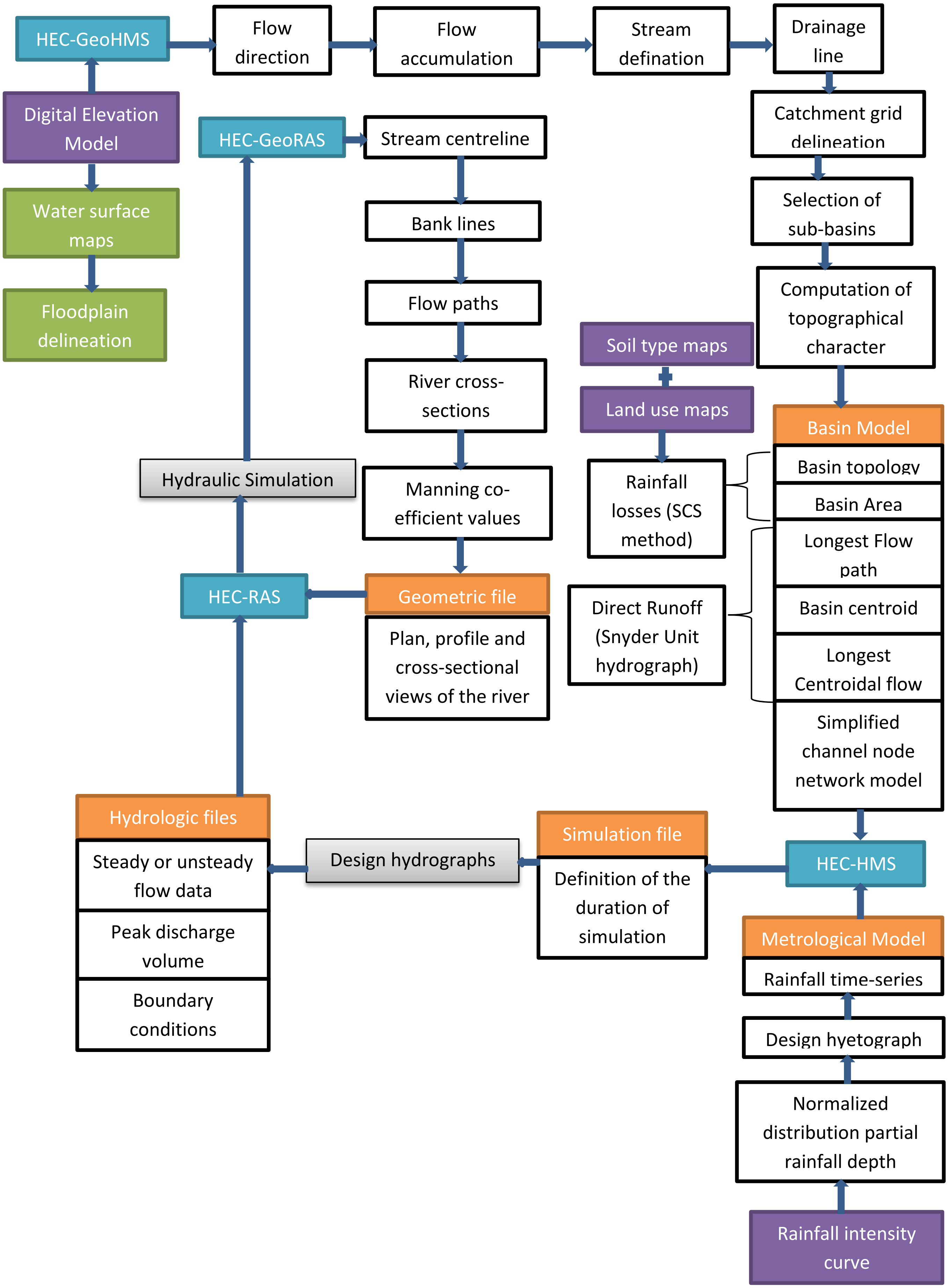


Figure 3-7: Flow chart of Floodplain Mapping

3.2. Data Collection and Analysis

Data collection is vital and requires the gathering of all necessary information for hydraulic analysis. This includes such information as topography and other physical features, land use and culture, any existing flood studies of the stream, historical flood data, basin characteristics, precipitation data, geotechnical data, historical high-water marks, existing structures, channel characteristics and environmental data.

The Hydrological data were collected from the FDRE Minister of Water, Irrigation and Electricity. Meteorological data were also collected from National meteorological agency. The digital elevation model (DEM) and land use were also downloaded from the United States Geological Survey (USGS) and the Corn Land Cover Facility (CLCF), respectively.

3.2.1. Meteorological Data Availability and Processing

Before beginning any hydrological analysis, it is important to make sure that data are homogenous, correct, sufficient, and complete with no missing values. Errors resulting from lack of appropriate data processing are serious because they lead to bias in the final answers (Vedula & Mujumdar, 2005). Generally, data for floodplain mapping should be appropriately adjusted for inconsistency, corrected for errors, extended for insufficient, and filled for missing using different techniques.

Basically a clear understanding of the hydro-meteorological conditions of the area is one of the basic requirements of any water resource management study. For this particular research work Meteorological, Hydrological, and Digital Elevation Model (DEM) data setting was undertaken for Geray catchment and the corresponding floodplain area of Geray River.

Daily rainfall and flow, maximum and minimum temperature data of different record length for some stations were collected from National Meteorological Agency (NMA) and Ministry of Water and Energy.

3.2.2. Estimating Missing Precipitation

A number of methods have been proposed for estimating missing precipitation. The station average method is the simplest one. The normal ratio and quadrant method provide a weighted mean, with the former biasing the weights on mean annual precipitation at each gauge and the later having weights that depend on the distance between gauges where recorded data are available and the point where the value is required.

Normal ratio method is used in this research paper. The method is used when the normal annual precipitation of the index stations differ by more than 10% of the missing stations. This method assigns weights of each surrounding stations. (Sing, 1994). This is the case for the stations near the study area. The general formula for computing missing precipitation by this method is:

$$\boldsymbol{\phi_n = \frac{{\phi_n}^a}{r}\sum_{i=1}^{r}\left[\frac{\phi_i}{{\phi_{ni}}^a}\right]} \text{.................................} (1)$$

Where, ϕ-n is estimate of missing data for gauged station n ,ϕ-ni is measured rainfall values of surrounding station i, ,,ϕ-n.-a. is normal annual rainfall of station n, ,,ϕ-ni.-a. is normal annual rainfall of surrounding stations i, ,ϕ-i is the observed value at station i, and r is number of surrounding stations.

Table 3: List of selected gauging stations used for this study

No.	Station Name	Latitude	Longitude	Elevation	Database
1	Felege Birhan	38.07	10.75	2680	1979-2015 (22)
2	Debre work	38.13	10.73	2740	1970-2015(27)
3	Mehal Meda	37.43	10.25	3040	1975-2015 (26
4	Debre Markos	37.67	10.33	2515	1954-2015 (52)
5	Finote Selam	37.27	10.68	1900	1961-2015(22)

3.2.3. Data Consistency and Homogeneity

Estimating missing precipitation is one problem that hydrologists need to address. A second problem occurs when the catchment rainfall at rain gages is inconsistent over a period of time and adjustment of the measured data is necessary to provide a consistent record. The trend of the rainfall records at a station may slightly change after some years due to a change in the environment (or exposure) of a station either due to coming of a new building , fence, planting of trees or cutting of forest nearby which affect the catch of the gauge due to change in the wind pattern or exposure. A consistent record is one where the characteristics of the record have not changed with time. Inconsistency may result from: change in gauge location, exposure, instrumentation, or an observational procedure is not real and on time.

To overcome the problem in consistency a technique most widely applied called double mass curve is used. Double-Mass Curve (DMC) analysis is a graphical method for identifying or adjusting inconsistencies in a station record by comparing its time trend with those of other stations nearby (Shaw, 1988).

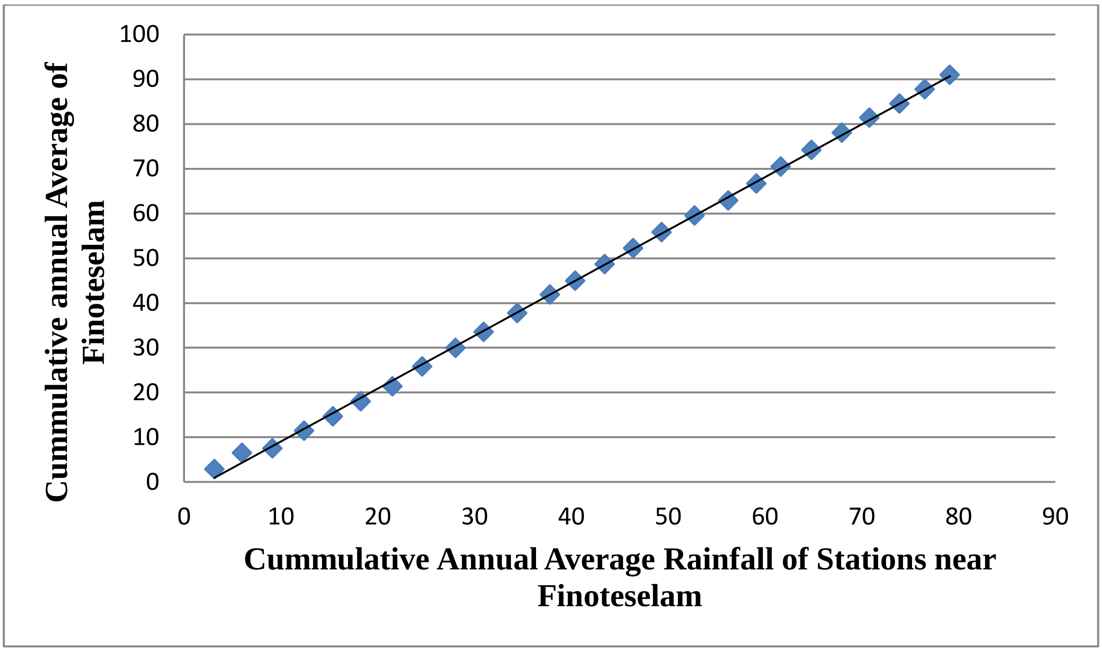


Figure 3-8: DMC of Finote Selam Vs. the four stations selected

To check Homogeneity of selected stations In order to select the representative meteorological station for the analysis of areal precipitation on Geray River, checking homogeneity of group stations is essential, the homogeneity of the selected gauging stations monthly rainfall records were carried out by non-dimensioning using equation (Linsley, 1983):

$$\boldsymbol{P_i = \frac{\bar{P}_i}{\bar{P}} * 100} \text{.................................} (2)$$

Where: - P_i=Non dimensional Value of PPT for the month i

$\bar{P}_i$ = Over years averaged monthly precipitation for the station i

$\bar{P}$ = The over years average yearly precipitation of the station

3.2.4. Areal Precipitation

A rain gauge records the rainfall at a single point. This point rainfall record has to be converted to aerial rainfall. The average depth of precipitation over the area under the area under consideration is one of the most important parameter in hydrological analysis.

There are many methods available to determine the areal rainfall over the catchments from the rain gauge measurement: Arithmetic Mean, Thiessen Polygon, Isohyetal, Grid Point, Percent Normal, Hypsometric, etc. are available for estimating average precipitation over a drainage basin (Shaw, 1988). Choice of methods requires judgment in consideration of quality and nature of the data, and the importance, use, and required precision of the result.

In order to determine the average depth of rainfall contribution from the Geray River catchment was analysed using a Thiessen polygon method which is most widely used method compared to others and is used in this research paper. In this method, weights are given to all the measuring gauges on the basis of their areal coverage of the watershed, thus eliminating the discrepancies in their spacing over the basins. All the stations in and around the basins are considered and a linear variation in the precipitation between two gauge stations is assumed.

The perpendicular bisector of these lines forms a pattern of polygons with one station in each polygon. The area with which each station is taken represents the area of its polygon, and this area is used as a factor for weighting the station precipitation. The contribution of the rainfall from each gauging station is limited by its weighing factor.

According to Thiessen, the average rainfall, R_{areal} over the area can be computed from:

$$\boldsymbol{R_{areal} = \sum_{i=1}^{n} \frac{R_i A_i}{A_t}} \quad \text{.................................} \ (3)$$

Where, R_i is the rainfall at station i, A_i is the polygon area of station i, At is total catchment area, and n is the number of stations. The area functions A_i/A_t are known as the Thiessen coefficients and once they are determined for a given stable station network, the areal rainfall can be computed for the set of rainfall measurements.

3.2.5. Flow data

The daily discharge of the study area has no stream gauge therefore, daily discharge was determined using an area ratio method.

In the absence of sufficient record length or for completely ungagged areas, data extension and generation can be employed with similarity of the neighbouring catchment (Awlachew, 2000).

To determine the overall discharge at the confluence of Geray River, streamflow data was transferred to the site of interest using area ratio methods and convolution equation. The recommended guidelines for area ratio method to assess the available dependable flow for the potential assessment purpose is,

$$\boldsymbol{Q_{ungauged}} = \left(\frac{\boldsymbol{A_{ungauged}}}{\boldsymbol{A_{gauged}}}\right)^{\boldsymbol{n}} * \boldsymbol{Q_{gauged}} \quad \text{.................................} (4)$$

Where: - $Q_{ungauged}$ - Discharge at the site of interest

Q_{gauged} - Discharge at the gauge site

$A_{ungauged}$ - Drainage area at the site of Interest

A_{gauged} - Drainage area at the gauging site

n - Varies between 0.6-1.2

If $A_{ungauged}$ is within 20% of the A_{gagged} (0.8$\leq \frac{A_{ungauged}}{A_{gauged}} \leq$ 1.2) then n=1 to be used. The estimated discharge at the site will be within 10% of actual discharge (Awlachew, 2000).

3.2.6. Data filling and Consistency

Before developing a stream flow for Geray river using the leza river, missing flow data records for the sub basin must be filled, and is done by developing correlation (which is a measure of the strength of association between two continuous variables) between the station with missing data and any of the adjacent stations with the same hydrological features and common data periods. Consistency and extension of flow data is analysed by regression technique.

Data consistence for this paper was done with SPSS software and Microsoft excels for comparison of results.

3.2.7. Evapotranspiration

Evapotranspiration is a collective term that includes evaporation from the land surface and transpiration from vegetation cover. Generally it means that water removed from the watershed (Monteith, 1965).

A relatively accurate estimation of evapotranspiration is a quite essential element in the floodplain mapping and modeling and the study of impact of climate change. There are two common methods in calculating evaporation. These are the Penman-Monteith method (Monteith, 1965), the Priestley-Taylor method (Priestley and Taylor, 1972) and the Hargreaves method (Hargreaves & Samani, 1985). One of the three methods is selected to calculate the potential evapotranspiration from the watershed depending up on the data available. The model will also read if a separate daily PET values are applied for potential evapotranspiration method.

The data requirements for the application of these three potential evapotranspiration methods are very different. The Penman-Monteith method requires solar radiation, air temperature, relative humidity and wind speed. The Priestley-Taylor method requires solar radiation, air temperature and relative humidity. The Hargreaves method requires air temperature only. Because of the data availability for this paper the Hargreaves method is selected. The detailed steps are shown below (Neitsch, 2005).

$$\boldsymbol{ET_o = 0.0023(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5} R_a} \quad \text{................................} \ (5)$$

Where: T_{mean} - the mean of the daily maximum (T_{max}) and minimum temperatures (T_{min}) rather than as the average of hourly temperature measurements.

$$\boldsymbol{T_{mean} = \frac{T_{max} + T_{min}}{2}} \quad \text{................................} \ (6)$$

T_{max} - Daily maximum temperatures.

T_{min}- Daily minimum temperatures.

R_a- Daily extra-terrestrial (solar) radiation, it is the solar radiation received at the top of the earth's atmosphere on a horizontal surface. It is given by:

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)] \quad (7)$$

Where

R_a - Extra-terrestrial radiation [MJ m^{-2} day^{-1}]

G_{sc}- Solar constant = 0.0820 MJ m^{-2} min^{-1}

d_r- Inverse relative distance Earth-Sun and it is given by:

$$d_r = 1 + 0.0033 Cos(\frac{2\pi}{365} J) \quad (8)$$

Where J is the number of the day in the year between 1 (1 January) and 365 or 366 (31 December)

ω_s - Sunset hour angle and it is given by:

$$\omega_s = arccos[-\tan(\varphi)\tan(\delta)] \quad (9)$$

φ - Latitude of the station [rad]

δ – Solar decimation (rad) and it is given by:

$$\delta = 0.409\sin(\frac{2\pi}{365} J - 1.39) \quad (10)$$

3.3. Developing Geometric Data

Developing a good hydraulic model begins with an accurate geometric description of the surrounding of the study area, especially the channel geometry. Channel geometry typically dictates flow in river systems; therefore, only highly accurate DTMs describing the channel geometry were considered for the basis of performing hydraulic analysis. Further, RAS layers were created with thoughtful evaluation of the river hydraulics as governed by the terrain (Alemu, 2007).

The RAS GIS import file consists of geometric data necessary to perform hydraulic computations in HEC-RAS. Cross-sectional elevation data derived from an existing Digital Terrain Model (DTM) of the channel and surrounding land surface, while cross-sectional properties are defined from points of intersection between RAS Layers. The DTM may be created in the form of TIN or GRID. In this particular thesis the DTM was created using TIN (triangulated irregular network).

The required RAS Layers created include the stream centrelines and XS cut Lines. Optional RAS Layers include the main channel banks, flow path centrelines, land use, levee alignment, blocked obstructions storage areas. Hydraulic structure layers was created for bridges/culverts, inline structures and lateral structures. Geometric data and cross-sectional attributes were extracted to generate a data file that contains:

- River, reach, station identifiers;
- Cross-sectional cut lines and surface lines;
- Main channel bank station locations;
- Reach length for the left overbank, main channel and right over bank;
- Roughness coefficients;
- Levee positions and elevations;
- Ineffective flow areas and obstructions to flow;
- Bridge/culvert cut line locations and elevation profiles;
- Inline and lateral structure locations and elevation profiles;
- Storage area locations and elevation-volume relationships; and
- Storage area connection location and elevation profiles.

3.4. Development of DTM

An existing DTM that represents the channel bottom and the adjacent floodplain areas was required by HEC-GeoRAS. The DTM may be in the form of triangulated irregular network (TIN) or a GRID. A TIN was the preferred method for surface modeling for river hydraulics because it is well suited to represent linear features, such as channel banks, roads and levees and will allow developing a more refined cross-section data. However, all inundation mappings are performed using GRID analysis. The terrain model should be constructed to completely depict the floodplain of the interest from elevation point data and breaklines identifying linear features of the landscape. Elevation data will be extracted from DTM for each cross-section. The DTM will also be used for floodplain mapping t determine floodplain boundaries and to calculate inundation depth

DEMs exist in grid (raster cell) format which can be displayed within ArcGIS, if the proper extensions are installed. The quality of this data is based on its resolution, or cell size.

The smaller the cell is, the greater the resolution and accuracy. However, the smaller the cell size, the greater the memory and computation requirements. The usefulness of DEMs for developing terrain models should be determined based on the cell size and the level of hydraulic analysis to be performed. The more approximate the analysis is to be, the greater the cell size that may be used. This can best be represented by TIN of the study area.

The TIN is generated from the spot heights acquired from different sources in ArcGIS which included:

1. Google earth surveyed data collected along the two river banks, with good accuracy.
2. The spot heights of the flood plains taken from the surveyed data which extend approximately far from both the left and right bank stations and cover the floodplain if topography permits.
3. River bed cross section elevation data.

3.5. TIN of the Study Area

In one dimensional hydraulic modeling river and floodplain topography are represented as continuous surface. The representation of the river and floodplain is by the use of the TIN generated from the intersection of actual field data and the existing DEM of the study area.

The surveyed data contains information about the river layers (centrelines, right bank and left bank). The spot elevations are processed in ArcGIS to form shape files for the layers. When creating these shape files, there are meandering points which are lack of data for further processing. The points are then filled with successive interpolation and with additional field surveys. With the field survey processed in ArcGIS, shapefile of the stream centrelines and bank lines are created.

For high accuracy of stream and floodplain representation, a high resolution DEM is prerequisite. Previous works on the area are carried out by using DEM 30. But this may not give appropriate result as required. In this paper DEM 30 is used to create TIN. The DEM is then intersected with field data to have greater accuracy for construction of river topography and other properties.

The TIN processed is assumed to represent the entire floodplain. From the approach the elevation values derived from the DEM is used to represent flood plain whereas the values from actual field survey to river channel. This is because of the fact that there may be water flowing during the DEM processing.

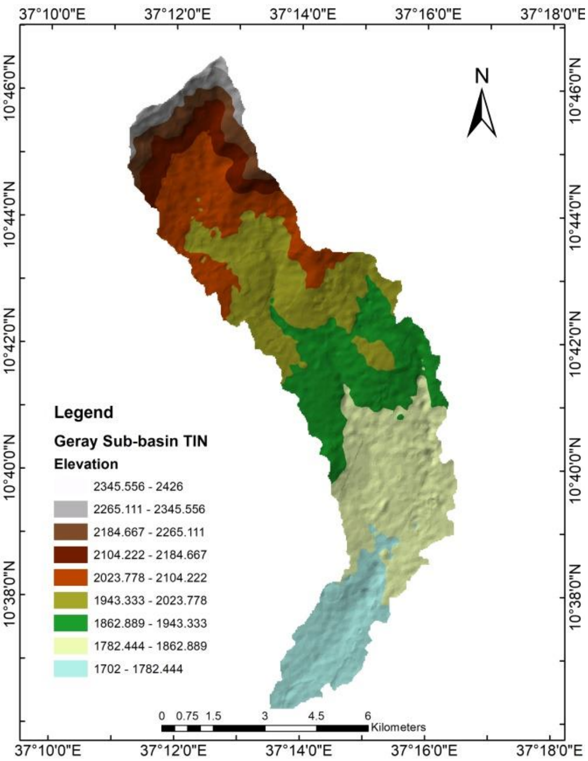


Figure 3-9: TIN of the study area

3.6. Terrain Processing using Arc Hydro and HEC-GeoHMS

3.6.1. HEC-GeoHMS Geospatial Data Processing

HEC-GeoHMS is a set of ArcGIS tools specifically designed to process geospatial data and create input for the HEC-HMS. HEC-GeoHMS provides the connection for translating GIS spatial information in to model files for HEC-HMS. The GIS capability is for data formatting, processing and coordinate transformation. Currently, HEC-GeoHMS operates on DEM to derive sub-basin delineation and to prepare a number of hydrologic units. HEC-HMS supports these hydrologic inputs as starting point for hydrologic modeling. In this paper it is intended to derive parameters like: Curve Number, Basin Lag, and Time of concentration and Loss.

3.6.2. Terrain Processing Using Arc-Hydro

The first step in doing any kind of hydrologic modeling involves delineating streams and watersheds, and getting some basic watershed properties such as area, slope, flow length, and stream network density. Traditionally this was done manually by using topographic/contour maps. With the availability of digital elevation models (DEM) and GIS tools, watershed properties can be extracted by using automated procedures.

The processing of DEM to delineate watersheds is referred to as terrain pre-processing. There are several tools available online for terrain pre-processing. In this study, Arc-Hydro (tools version that works with ArcGIS 10.3) was used to process a DEM to delineate watershed, sub-watersheds, stream network and some other watershed characteristics that collectively describe the drainage patterns of a basin. The results from terrain processing can be used to create input files for many hydrologic models using HEC- Geo HMS.

3.7. Overview of Model Simulation

Data models are central to the application of information technology because they are the means by which the real world is represented inside a computer (Gary, 2016).

The model starts with data processing and acquisition of the HEC-HMS. The data required for the model is derived from different hydrological components. This hydrologic representation imported into HEC-HMS is then combined with precipitation data and control specifications to create flow and time series data for use in a Hydrologic Data Model HEC-HMS. The flow and time series data from HEC-HMS is imported into the hydraulic model HEC-RAS along with its geometry data to develop water surface profiles. To close the loop, data is then once again used in ArcGIS with a HEC-GeoRAS extension from HEC-RAS to create a visual model used to delineate floodplain.

3.8. Hydrologic Modeling with HEC-HMS

HEC-HMS modeling may be taken considering different time series values such as daily, hourly, annually and even in minute. Accuracy of the model output is high if it is in reverse order. Although most flood studies are undertaken considering hourly time steps, there are cases where daily data are taken. In this paper both daily data by gage weight method and frequency storm method are considered to compare the output result for each. The first portion covers modeling on daily basis.

The rainfall has no full data on any station used for missing data thus making the result unreliable. Consequently, HEC-HMS outputs considering daily data using gage weight method and frequency storm method are used for further modeling approaches. Then the model output is compared with frequency analysis results which are selected by software called easy fit.

3.8.1. Input data and Model Components

The main input data used for HEC-HMS are areal precipitation, Evapotranspiration, observed flow, base flow and different watershed characteristics obtained from HEC-GeoHMS.

An HEC-HMS simulation is defined by three components: the Basin Model, the Meteorological Model, and the Control Specifications. The Basin Model contains a schematic consisting of any combination of the seven objects if any of them existed in the watershed (sub-basin, reach, junction, source, sink and reservoir).

The Basin Model stores information about the properties and connectivity of the objects in the schematic. In this research paper only the first three components are used. The Meteorological Model contains time series information consisting of rainfall and evaporation data. These data are associated with rain gages that the user defines in the Meteorological Model. The Control Specifications component defines simulation properties such as duration and time step.

The HEC-HMS model for the Geray catchment is done considering and dividing the Basin in to three sub-basin. The calibrated model is used for runoff generation for different frequency storms. In this research paper the gage weight method is selected.

3.8.2. Modeling Approach

3.8.2.1. Basin Model

A general basin model consisting of sub-basin 1, sub-basin 2, and sub-basin 3 is set up in HEC-HMS generated with ArcGIS for the study area. In addition to three sub-basins, an outlet element is used in the basin model to relate the simulated flow to the historical observed total flow of the sub-basins. In this particular study for the respective sub basins, depending on the availability of time and data requirement, simulation is done with Deficit and constant loss method, Clark unit hydrograph and Monthly constant base flow condition (David Ford, 2008).

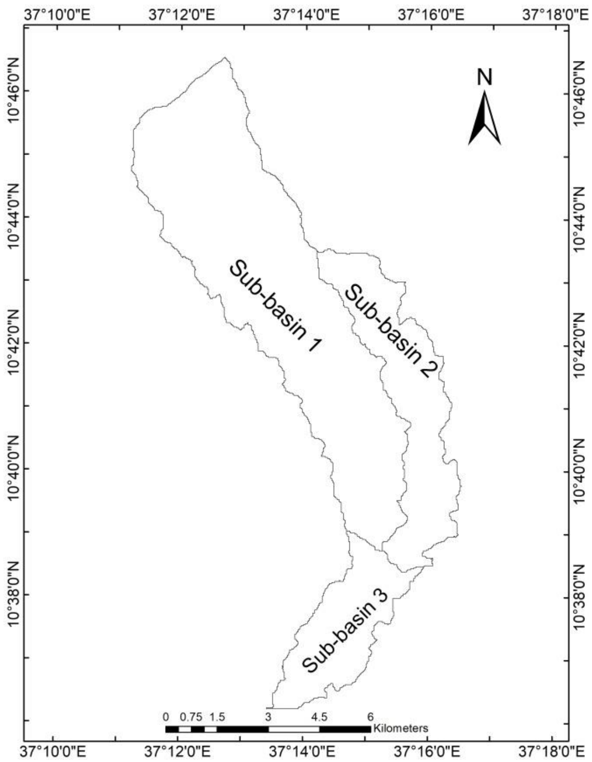


Figure 3-10: Sub-basins of the Geray catchment

A. Loss determination

The term loss refers to the amount of rainfall infiltrated into the soil. HEC-HMS supports the most common methods for calculating losses–such as initial/constant, SCS Curve No., gridded SCS Curve No., and the Green and Amps, and provides a moisture depletion option for simulations over extended periods of time (David Ford, 2008).

In this paper for gage weight method the SCS curve number loss method was chosen because the soil conservation service (SCS) curve number (CN) model estimates precipitation excess as function of cumulative precipitation, soil cover, land use, and antecedent moisture, using the following equation:

$$Q = \frac{(P-I_a)^2}{P-I_a+S} \qquad (11)$$

Where Q is accumulated direct runoff, mm, P accumulated rainfall (potential maximum runoff), mm, Ia initial abstraction including surface storage, interception, and infiltration prior to runoff, mm and S potential maximum retention, mm. Until the accumulated rainfall exceeds the initial abstraction, the precipitation excess; and hence the runoff, will be zero.

The relationship between Ia and S was developed from experimental catchment area data. It removes the necessity for estimating Ia for common usage. The empirical relationship used in the SCS runoff equation is:

$$\boldsymbol{I_a = 0.2\, S} \qquad (12)$$

Soil storage or retention Volume, S is related to the soil and cover conditions of the catchment area through the CN. CN has a range of 0 to 100, and S is related to CN by:

$$\boldsymbol{S = 25.4\left(\frac{1000}{CN} - 10\right)} \qquad (13)$$

Therefore, by substituting the value basin curve number CN, which is determined from HEC-GeoHMS, Value of soil storage or retention volume S, is:

$$\boldsymbol{S = 25.4\left(\frac{1000}{CN} - 10\right)} \qquad (14)$$

B. Transform method

Runoff transformations convert excess precipitation on a sub-basin to direct runoff at the sub-basin outlet. Again, HEC-HMS allows runoff transformation determinations using lumped or linear distributed approaches (David Ford, 2008).

Similarly, the SCS Unit Hydrograph model for direct runoff computation was chosen because of the model is based upon averages of UH derived from gaged rainfall and runoff for larger number of small agricultural watersheds.

SCS unit hydrograph is a dimensionless, single-peaked UH. This dimensionless UH expresses the UH discharge, U_t, as a ratio to the UH peak discharge, U_p

C. Base flow

With regard to base flow, constant monthly base flow method was used for its suitability to the study areas. This is because of it's the simplest baseflow model in HEC-HMS program; and it represents baseflow as a constant flow; this may vary monthly. The initial value before calibration was taken as the average of minimum flow.

D. Routing method

Muskingum routing is used to route the channel for continuous hydrological modeling. Automated calibration (optimization) was found to give optimum and reliable model parameters (David Ford, 2008).

The objective function used for automated calibration (optimization) is the Peak-Weighted RMS Error. The HEC-HMS model has two optimization algorithms: Univariate gradient and Nealder and Mead search algorithm. Univariate gradient search algorithm is used for this study (David Ford, 2008).

The parameters optimized is then used to represent the entire catchment and calibrated accordingly. This may be due to the smaller area of the Geray catchment and the similarity in land use of the study area.

3.8.2.2. Meteorological Model

After the basin model is fully entered the meteorological modeling will follow and the specified hyetograph method was chosen for this paper. And for evapotranspiration modeling the specified evapotranspiration method was chosen.

The gage weight method is a meteorological method used in meteorological model to produce a runoff from given timely precipitation data.

3.8.3. Model Calibration

The goal of calibration is to identify reasonable parameters that yield the best fit of computed to observed hydrograph, as measured by one of the objective functions (David Ford, 2008).

According to the Canadian Foundation for Climatic and Atmospheric sciences (CFCA), a single event hydrologic modeling should be used for simulating storm and frontal rainfall induced floods. Continuous modeling approach should be then employed for snow melt and mixed rainfall snowmelt flooding, as well as for simulating the prolonged periods of summers of low flows if there is a snow melt around the study area since there has never been a snow occurred.

The value of each parameter found in HEC-HMS must be specified to use the model for estimating runoff volume and routing hydrographs. Some of the model parameters can’t be estimated by observation or measurement of the watershed characteristics. For example the parameter ‘x’ and ‘k’ in the Muskingum routing model can’t be measured but can be estimated approximately for limited cases.

How then can the appropriate values for the parameters be selected? If rainfall and streamflow observations are available, calibration is the answer. Calibration uses observed hydro meteorological data in a systematic search for parameters that yield the best fit of the computed results to the observed runoff.

This search is often referred to as optimization. Optimization begins from initial parameter estimates and adjusts them so that the simulated results match the observed streamflow as closely as possible. To compare a computed hydrograph to an observed hydrograph, the program computes an index of the goodness-of-fit.

Algorithm included in the program search for the model parameters that yield the best value of an index, also known as objective function. Out of four objective functions in HMS, Peak-weighted root mean square error is selected for this study because it compares all ordinates, squaring differences and it weights the squared differences, the weight assigned to each ordinate is proportional to the magnitude of the ordinate. Ordinates greater than the mean of the observed hydrograph are assigned a weight greater than 1.00 or smaller, a weight less than 1.00. The peak observed ordinates is assigned the maximum weight. The sum of weighted squared difference is divided by the number of computed hydrograph ordinates; thus yielding the mean squared error. Taking the square root yields the root mean squared error. The function is an implicit measure of comparison of the magnitudes of the peaks, volumes, and time of peak of the two hydrographs (David Ford, 2008).

As noted earlier, there is in need of a mathematical searching parameter that minimizes the value of objective function. The univariate-gradient search algorithm was chosen for this study because it makes successive corrections to the parameter estimate. That is, if X^K represents the parameter estimate with objective function $f(X^K)$ at iteration k, the search defines anew estimate X^{k+1} as:

$$\boldsymbol{x^{k+1}} = \boldsymbol{x^k} + \Delta\boldsymbol{x^k} \text{.................................} (15)$$

In which, Δx^k = the correction to the parameter, the goal of the search is to select Δx^k so the estimates move toward the parameter that yields the minimum value of the objective function. One correction does not, in general, reach the minimum value, so this equation is applied recursively (David Ford, 2008).

3.8.4. Model Efficiency/Performance

The performance of a model must be evaluated on the extent of its accuracy, consistency and adaptability. A forecast efficiency criterion is therefore necessary to judge the performance of the model.

Assessing performance of a hydrologic model (Krause, Boyle, & Base, 2005) requires subjective and/or objective estimates of the closeness of the simulated behaviour of the model to observations. For the Geray catchment study, model simulation has been evaluated using efficiency criteria such as coefficient of determination (R^2) and Nash-Sutcliffe model efficiency coefficient (NSE) (Nash & Sutcliffe, 1970).

The R^2 coefficient and ENS simulation efficiency measure how well trends in the measured data are reproduced by the simulated results over a specified time period and for a specified time step. The range of values for R^2 is 1.0 (best) to 0.0. The statistical index of modeling efficiency (ENS) values range from 1.0 (best) to negative infinity.

The Nash and Sutcliffe (ENS) efficiency equation is given by:

$$\boldsymbol{E_{NS} = 1 - \frac{\sum_{i=1}^{n}(q_{oi}-q_{si})^2}{\sum_{i=1}^{n}(q_{oi}-\overline{q}_o)^2}} \text{.................................} (16)$$

And the standard R^2 is given by:

$$\boldsymbol{r^2 = \frac{[\sum_{i=1}^{n}(q_{si}-\overline{q}_s)(q_{oi}-\overline{q}_o)]^2}{\sum_{i=1}^{n}(q_{si}-\overline{q}_s)^2 \sum_{i=1}^{n}(q_{oi}-\overline{q}_o)^2}} \text{.................................} (17)$$

Nash–Sutcliffe efficiency can range from -∞ to 1. An efficiency of 1 (E = 1) corresponds to a perfect match of modelled discharge to the observed data. An efficiency of 0 (E = 0) indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero (E < 0) occurs when the observed mean is a better predictor than the model or, in other words, when the residual variance (described by the numerator in the expression above), is larger than the data variance (described by the denominator). Essentially, the closer the model efficiency is to 1, the more accurate the model is (Liu, Lee, & Jordan, 2016).

R-squared is the fraction by which the variance of the errors is less than the variance of the dependent variable. It is called R-squared because in a simple regression model it is just the square of the correlation between the dependent and independent variables, which is commonly denoted by “r”. In a multiple regression model R-squared is determined by pairwise correlations among all the variables, including correlations of the independent variables with each other as well as with the dependent variable. An increase in R-squared from would reduce the error standard deviation by about in relative terms. This measure estimates how well the dispersion of the measured data is predicted by the model (Liu, Lee, & Jordan, 2016).

3.8.5. Model Validation

Model Validation is the process of determining if a proposed model accurately represents a physical process and provides predictive capability. Or in other word it is the process of determining if a set of model parameters estimated during calibration performs well under different through similar conditions (David Ford, 2008).

3.8.6. Modeling by Frequency Storm Method

With the input from HEC-GeoHMS and some edition from the main HEC-HMS, the model is simulated for rainfall intensity of 2, 10, 50, and 100 years return periods. The frequency intensity values are found from the Ethiopian Roads Authority drainage manual (Ethiopian Road authorities, 2001).

The study areas meteorological station which is Finote Selam station is found in A2 meteorological area. Therefore, rainfall intensity is selected from the graph of A2 ERA drainage manual shown in figure 3-12.

Table 4: IDF table for the study area

Source: **(Ethiopian Road authorities, 2001)**

Duration	RF depth for various return period				
(hr)	**2**	**10**	**25**	**50**	**100**
1	22.51	32.28	37.19	40.79	44.42
2	28.53	40.91	47.14	51.69	56.29
3	32.05	45.96	53.13	58.07	63.24
6	38.22	54.81	63.42	69.25	75.42
12	44.76	64.18	73.7	81.1	88.32
24	52	74	85.7	94	102

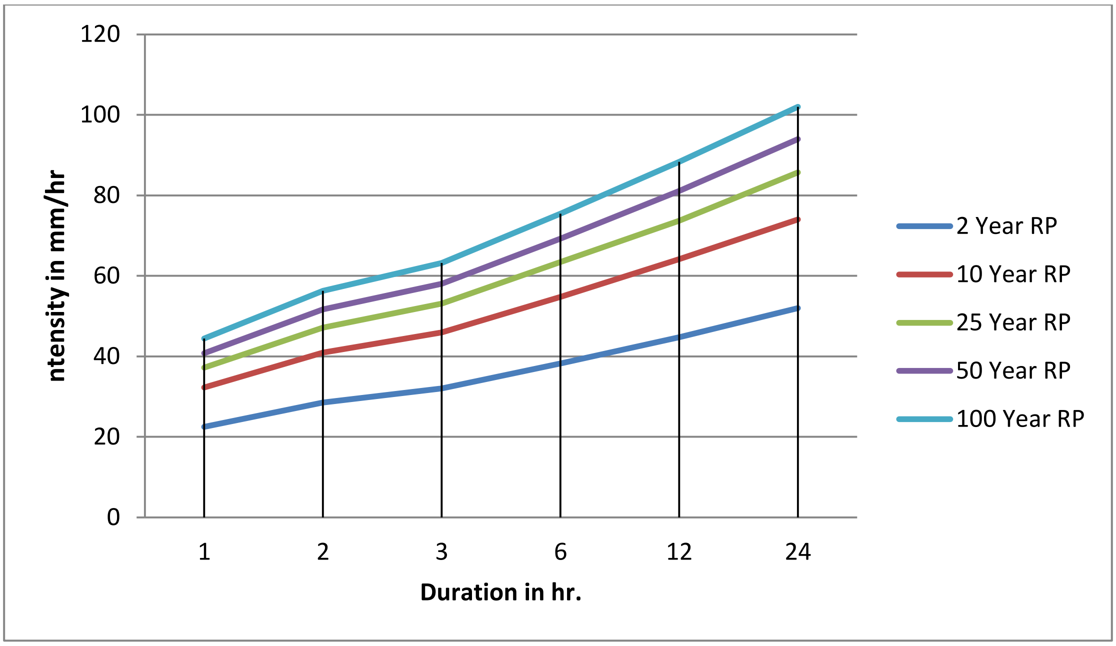


Figure 3-11: IDF Curve of Rainfall the Study area

Source: **(Ethiopian Road authorities, 2001)**

3.9. Flood Frequency Analysis

Frequency analysis has been applied to estimate the quantiles for the annual maximum rainfall and flood data. The objective of frequency analysis of hydrologic data is to relate the magnitude of extreme events to their frequency of occurrence through the use of probability distributions (Chow, 1988).

Evaluating flood frequency and determining the design flood are the final goals for hydrological analysis and the beginning of integrated flood control (Stedinger & Griffis, 2012). A design flood is used in comprehensive flood management to assess the flood defence capacities of facilities and to protect human lives and properties within a watershed (Rogger, et al., 2012).

3.9.1. Normal Distribution

The normal distribution arises from the central limit theorem, which states that if a sequence of random variables X_i are independently and identically distributed with mean μ, and variance σ^2, then the distribution of the sum of a such random variables, $Y = \sum_{i=1}^{n} X_i$, tends towards the normal distribution with mean $n\mu$ and variance $n\sigma^2$ as n becomes large, The important point is that this is true no matter what the probability distribution function of X is. The main limitations of the normal distribution for describing hydrologic variables are that it varies over a continuous range [$-\infty, \infty$], while most hydrologic variables are nonnegative, and that it is symmetric about the mean, while hydrologic data tend to be skewed (Chow, 1988).

$$\boldsymbol{f(x) = \frac{1}{\sigma\sqrt{2\pi}} exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)} \text{................................ (18)}$$

Where the probability density function ranges between $-\infty \leq x \leq \infty$, and the equations for parameters in terms of the sample moments are: $\mu = \bar{x}, \sigma = s_x$.

The magnitude x_T of a hydrologic event may be represented as the mean μ, plus the departure Δx_T of the variant from the mean.

$$\boldsymbol{x_T = \mu + \Delta x_T} \text{................................ (19)}$$

The departure may be taken as equal to the product of the standard deviation of and a frequency factor K_T; that is, $\Delta X_T = \sigma K_T$

Frequency analysis begins with the calculation of the statistical parameters required for a proposed probability distribution by the method of moments from the given data. For a given return period, the frequency factor can be determined from the K-t relationship for the proposed distribution, and the magnitude X_T computed.

The frequency factor can be expressed:

$$\boldsymbol{K_T = \frac{X_T - \mu}{\sigma}} \quad \text{.................................} \ (20)$$

This is the same as the standard normal variable z defined in Eq. (11.2.9). The value of z corresponding to an exceedance probability of p (p = U7) can be calculated by finding the value of an intermediate variable w:

$$\boldsymbol{w = \left[ln\left(\frac{1}{p^2}\right)\right]^{1/2}} \qquad (\boldsymbol{0 \le p \le 0.5}) \text{.................................} \ (21)$$

Then calculating 'z' using the approximation,

$$\boldsymbol{z = w - \frac{2.515517 + 0.802853w + 0.010328w^2}{1 + 1.432788w + 0.189269w^2 + 0.001308w^3}} \ \text{.................................} \ (22)$$

The frequency factor K_T for the normal distribution is equal to z.

The observed flow histogram for normal distribution was graphed using the software Easyfit.

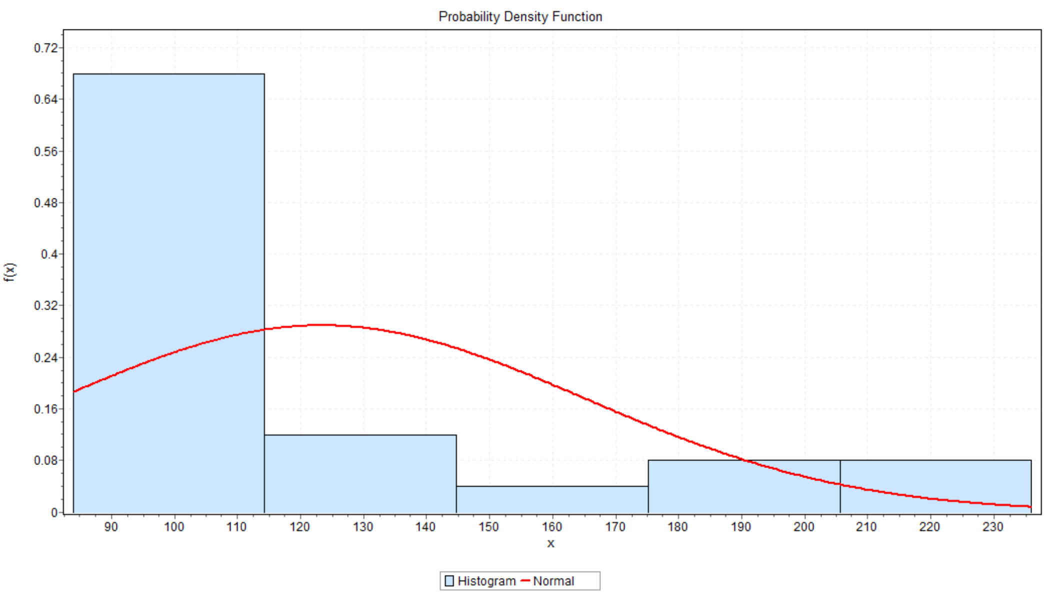


Figure 3-12: Histogram of observed flow for Normal distribution

3.9.2. Lognormal Distribution

If the random variable $Y = \log X$ is normally distributed, then X is said to be lognormally distributed. Chow (1954) reasoned that this distribution is applicable to hydrologic variables formed as the products of other variables since if $X = X_{1,} X_2 X_3 \cdots X_n$ then, $Y = log\, X = \sum_{i=1}^{n} X_i = \sum_{i=1}^{n} Y_i$, which tends to the normal distribution for large Z provided that the X; are independent and identically distributed (Freeze, 1975).

The lognormal distribution has the advantages over the normal distribution that it is bounded (X > 0) and that the log transformation tends to reduce the positive skewness commonly found in hydrologic data, because taking logarithms reduces large numbers proportionately more than it does small numbers. Some limitations of the lognormal distribution are that it has only two parameters and that it requires the logarithms of the data to be symmetric about their mean (Chow, 1988).

$$\boldsymbol{f(x)} = \frac{\mathbf{1}}{\boldsymbol{x\sigma\sqrt{2\pi}}}\left(-\frac{(\boldsymbol{y-\mu_y})^2}{\boldsymbol{2\sigma_y}^2}\right) \text{................................ (23)}$$

Where, Y=log X, and the probability density function ranges between $x > 0$, and the equations for parameters in terms of the sample moments are, $\mu = \bar{y}, \sigma = s_y$.

The magnitude x_T of a hydrologic event for the lognormal distribution, the same procedure applies except that it is applied to the logarithms of the variables, and their mean and standard deviation are used in the normal distribution equation.

The observed flow histogram for lognormal distribution was plotted using the software Easyfit.

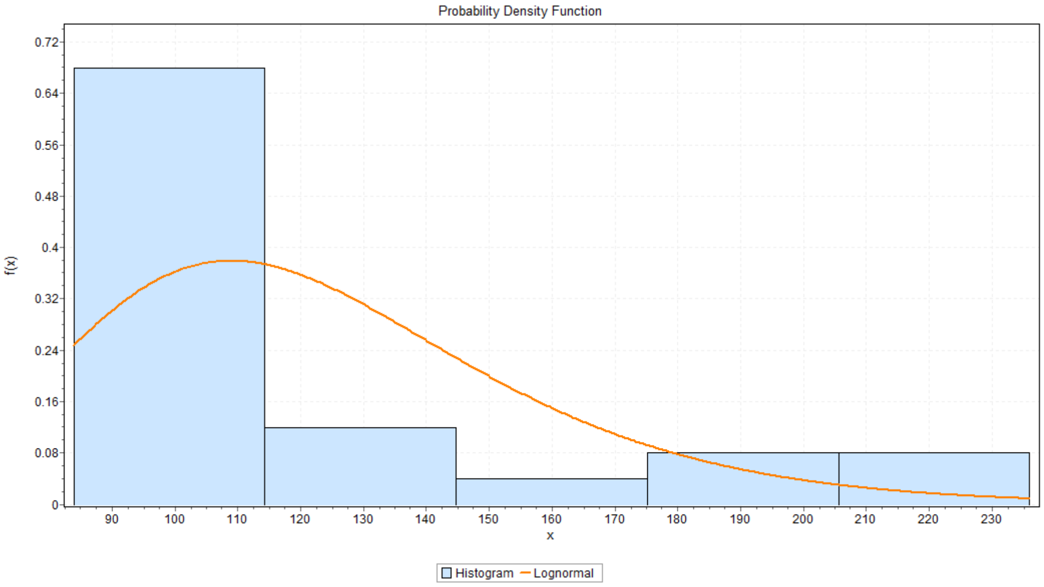


Figure 3-13: Histogram of observed flow for lognormal distribution

3.9.3. The Log-Pearson Type III Distribution

If log X follows a Pearson Type III distribution, then X is said to follow a log-Pearson Type III distribution. This distribution is the standard distribution for frequency analysis of annual maximum floods in the United States (Benson, 1968). As a special case, when log X is symmetric about its mean, the log-Pearson Type III distribution reduces to the lognormal distribution.

The location of the bound ϵ in the log Pearson Type III distribution depends on the skewness of the data. If the data are positively skewed, then $\log x \geq \epsilon$ and ϵ is a lower bound, while if the data arc negatively skewed, $\log x \leq \epsilon$ and ϵ is an upper bound (Bobee, 1975).

Its use is justified by the fact that it has been found to yield good results in many applications, particularly for flood peak data. The fit of the distribution to data can be checked using the χ^2 test, or by using probability plotting (Chow, 1988).

$$\boldsymbol{f(x)} = \frac{\lambda^{\beta}(y-\epsilon)^{\beta-1}e^{-\lambda(y-\epsilon)}}{x\Gamma(\beta)} \text{..................................} (24)$$

Where $y = \log x$ Γ is gamma function and probability density function ranges between $\log x \geq \epsilon$, and the equations for parameters in terms of the sample moments is, $\lambda = \frac{s_x}{\sqrt{\beta}}$, $\beta = \left[\frac{2}{C_s(y)}\right]^2$ and $\epsilon = \bar{x} = s_x\sqrt{\beta}$ assuming $C_s(y)$ is positive.

The magnitude x_T of a hydrologic event for Log-Pearson type III distribution, the first step is to take the logarithms of the hydrologic data y = log x. The mean μ, standard deviation σ and coefficient of skewness Cs, are calculated for the logarithms of the data. The frequency factor depends on the return period T and the coefficient of skewness Cs.

$\boldsymbol{K_T = z + (Z^2 - 1)k + \frac{1}{3}(Z^3 - 6z)k^2 - (Z^2 - 1)k^3 + zk^4 + \frac{1}{3}k^5}$................................
(25)

Where: $k = C_s/6$

The observed flow histogram for LP3 distribution was plotted using the software Easyfit.

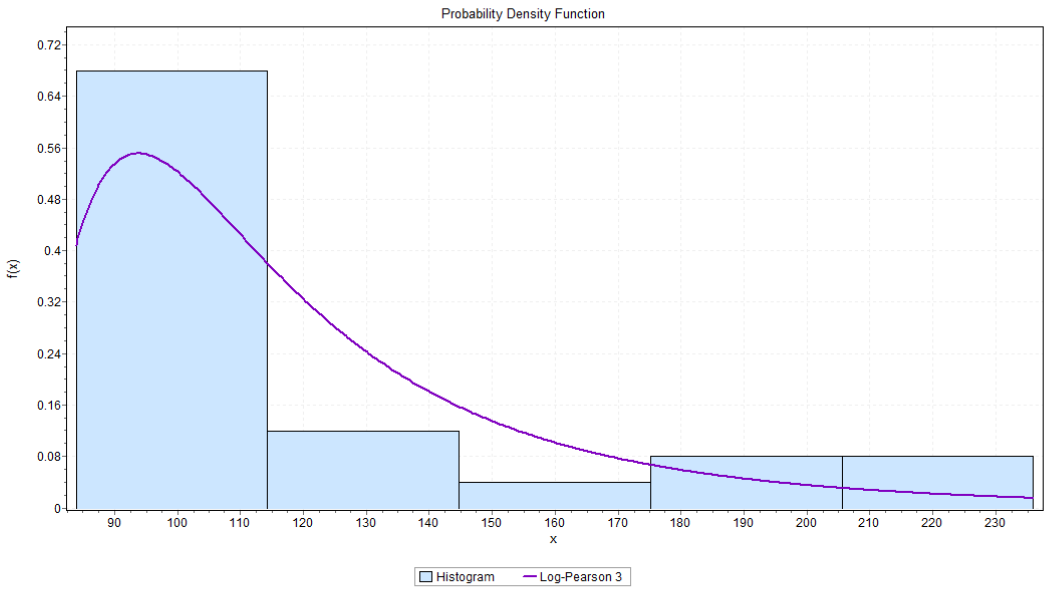


Figure 3-14: Histogram of observed flow for LP3 distribution

3.9.4. General Extreme Value Distribution

Extreme values are selected maximum or minimum values of sets of data. Distributions of the extreme values selected from sets of samples of any probability distribution converge to one of three forms of extreme value distributions, called

Types I, II, and III respectively, when the number of selected extreme values is large (Fisher & Tippett, 1928).

The probability distribution function for the GEV is:

$$\boldsymbol{F(x) = exp\left[-\left(1 - k\frac{x-u}{\alpha}\right)^{1/k}\right]} \qquad (26)$$

Where probability density function ranges between $-\infty < x < \infty$, and the equations for parameters in terms of the sample moments is, $\alpha = \frac{\sqrt{6}s_x}{\pi}$ and $u = \bar{x} - 0.5772\alpha$.

The observed flow histogram for GEV distribution was plotted using the software Easyfit.

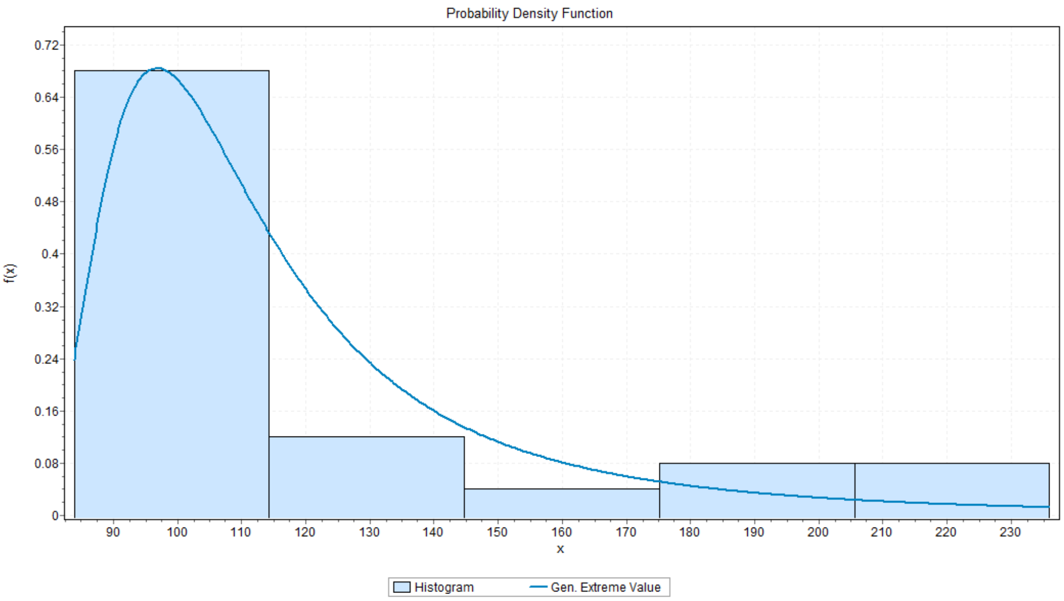


Figure 3-15: Histogram of observed flow for GEV distribution

3.10. Hydraulic Modeling with HEC-RAS

3.10.1. Input Data and Model Components

The main objective of the HEC-RAS program is quite simple- to compute water surface elevations at all locations for either a given set of flow data (steady flow simulation), or routing hydrographs through the system (unsteady flow simulation). The data needed to perform these computations are divided into the following categories: geometric data; steady flow data; unsteady flow data; sediment data and water quality data. One of the functions of the HEC-RAS program is to determine surface elevations at any point of interest. The data needed to perform these computations are separated into geometric data and steady flow data (boundary conditions). The input data for HEC-RAS is imported from ArcGIS which is discussed below (Gary, 2016).

3.10.1.1. Pre RAS Processing using HEC-GeoRAS

HEC-GeoRAS is an ArcGIS extension specifically designed to process geo-spatial data for use with the Hydrologic Engineering Centre River's Analysis System (HEC-RAS). The extension allows users to create Ras layers an HEC-RAS import file containing geometric attribute data from an existing digital terrain model (DTM) and complementary data sets. Water surface profile results may also be processed to visualize inundation depths and boundaries. HEC-GeoRAS extension for ArcGIS used an interface method to provide a direct link to transfer information between the ArcGIS and the HEC-RAS. The model uses the geometric attribute data from an existing digital terrain model (DEM) in TIN format and exported results from HEC-RAS model (Ackerman, 2009).

The goal of this subsection was to develop the basic spatial data required to generate the HEC-RAS Geometry Import File. The process required is the Generation of a digital terrain model (in this paper TIN is generated from field data and the DEM of the study area), Definition of base 2D spatial features and Generation of 3D spatial data and HEC-RAS Geometry Import File. Hence the DTM/TIN generated in section 4.3, the next step is 2D spatial feature definition.

3.10.1.2. 2D Spatial Features Definition

Hence the digital terrain representation (TIN) created; the next step is to extract the geometric information required by HEC-RAS. This step started with the delineation of a series of 2D spatial features corresponding to the stream centrelines, the left and right bank lines, the flow paths, and the cross sections along the streams. The contour lines may be helpful in this regard if the resolution of the TIN is poor.

In general, the delineation of cross sections located close to river junctions was not easy: each cross-section had to cross the stream centreline exactly once, the bank lines exactly twice (left and right), and the flow paths exactly three times (left, right and centreline) and they should not intersect each other.

3.10.1.3. Cross-section Geometry

Boundary geometry for the analysis of flow in natural streams is specified in terms of ground surface profiles (cross sections) and the measured distances between them. Cross sections should be perpendicular to the anticipated flow lines and extend across the entire flood plain (these cross sections may be curved or bent). For this research paper, it is made to extend to about a total of 8 km with 4 km at each stretch of the floodplain.

Cross sections are required at locations where changes occur in discharge, slope, shape or roughness; at locations where levees begin or end and at bridges or control structures such as weirs. Each cross section is identified by a Reach and River Station label. The cross section is described by entering the station and elevations (x-y data) from left to right, with respect to looking in the downstream direction (Gary, 2016).

The cross section of the Geray River is extracted both from Google earth and its counterpart digitized DEM/TIN. The study area TIN is also made from Google earth data and the DEM of the area. During the extraction, the Google earth data is assumed to represent the channel geometry than the DEM.

This is because of the fact that there may be water flowing during the processing of the DEM. On the other hand the resolution of the current DEM is less accurate for the river channel.

Although the DEM resolution is low for the channel, it is best representation for the floodplain. Integrating both data sources therefore has a greater accuracy than individual source.

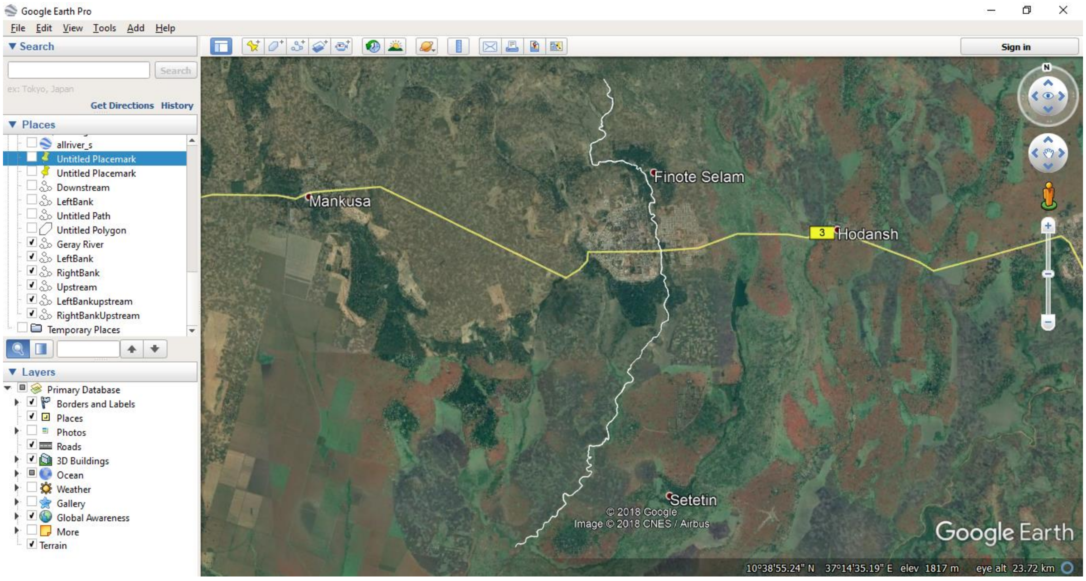


Figure 3-16: Geray River Cross-section taken from Google earth

Extraction of river cross section from freely available Google Earth software and validation of river cross section data in HEC-RAS was done.

Google Earth is a Geo-Browser that accesses aerial and satellite imagery, other geographic data over the internet and ocean bathymetry to represent the Earth as a three dimensional globe. It is also known as “Geographic Browser” because it maps the Earth by the aerial photography, the superimposition of images obtained from satellite imagery, and geographic information system (GIS) onto a 3D globe (Ujas Pandya, 2017).

In Google earth the degree of resolution of the satellite images are based on the points of interest and popularity, but most land is covered in at 15m of resolution. For the rest part of the Earth's surface, 3D images of terrain and buildings are available. Google Earth uses digital elevation model (DEM) data collected by NASA’s Shutter Radar Topography Mission (SRTM) (Ujas Pandya, 2017).

Using Google Earth software geometric data of total 20 km of Geray River from upstream to downstream was executed. Entire length of study area is divided into cross sections at every 200 meter interval. Distance of left bank and right bank of each successive cross section are also measured using Google earth software. Total 100 Nos. of cross sections are generated having minimum width 73 m and maximum width of 328 m along the length of river.

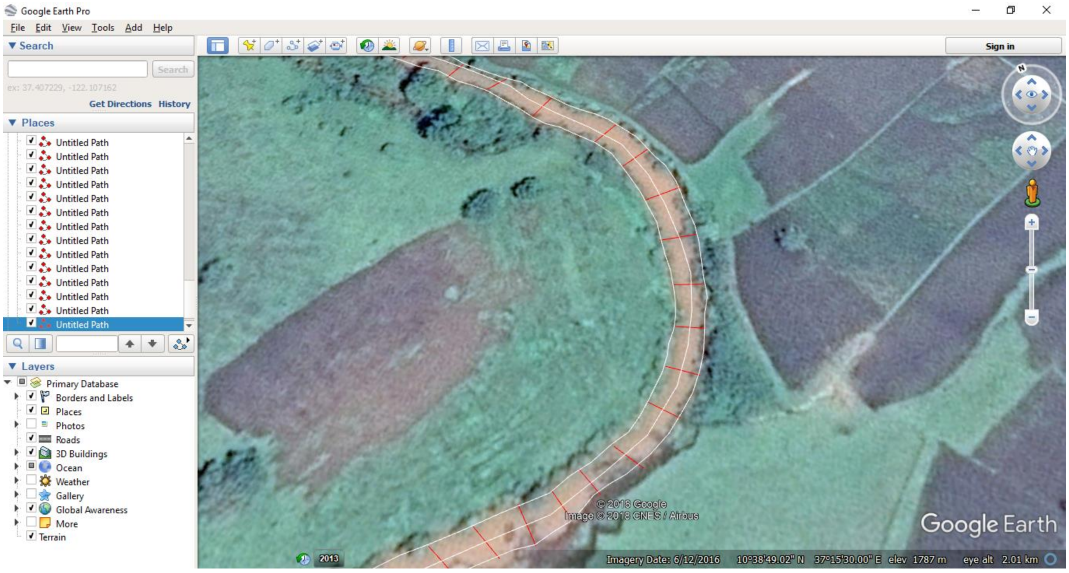


Figure 3-17: Geray River cross section in Google Earth

Before digitizing the cross section the stream layers must be made available. The layers are; stream centreline, flow path centreline, flow path lines (left and right) and bank lines and these layers overlay on the digitized RAS layer.

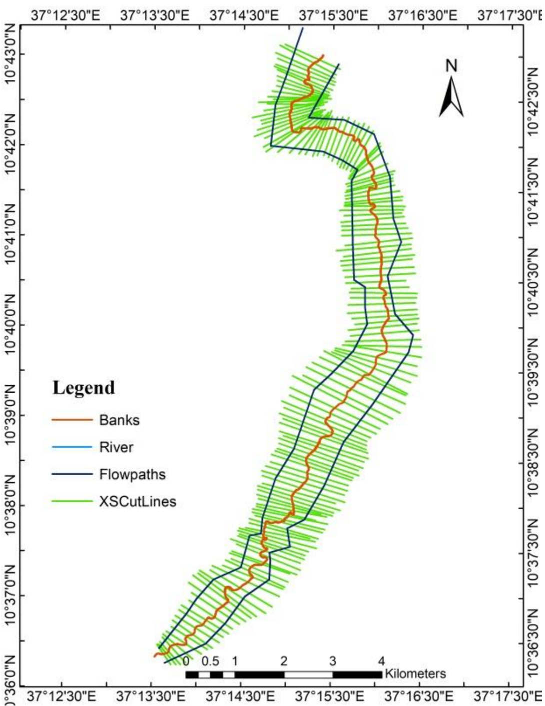


Figure 3-18: A digitized Geray River scheme with RAS layers

The above four features are extracted from prepared TIN of the study area. The TIN was generated from field survey of the area and DEM.

Accordingly the channel cross-section taken from Google earth is made to represent river cross section whereas the DEM to the floodplain. During digitizing shapefiles of the river or contour can be used to follow.

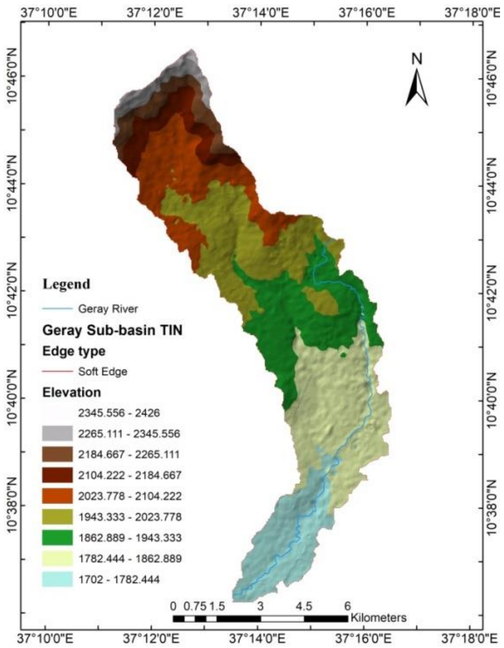


Figure 3-19: An underlying TIN and associated Geray River

Pre-processing by HEC-GeoRAS in ArcGIS is the first step in the extraction processes. The step is used in georeferencing and digitizing the stream layers for further use in HEC-RAS.

3.10.1.4. 3D Spatial Features and HEC-RAS Geometry Import File Generation

The 3D spatial data generation involved creation of 3D stream centrelines and 3D cross-sections, with Z values to define elevations. The Z values were extracted from the TIN.

Once generated, the 3D features identified the stream network and the HEC-RAS model layout. The generated cross section is then changed to polyline Z. The 2D point data is changed to the 3D polyline due to the extraction of elevation from the DTM/TIN.

3.10.2. Exporting to HEC-RAS

It is very important to edit and geo-reference all necessary layers in GIS. Although the HEC-RAS has an editing interface for the exported value, the GIS is a better way to reduce the error during post-RAS process (flood mapping and delineation). There are different options to leave or export RAS layers depending on their use and necessity. There may be errors during pre-RAS processes.

The bank stations which are made fit with the cross section points in GIS may not match when exported to HEC-RAS. In this case manual edition should be applied.

The exported cross section may not also be readable by the HEC-RAS. The problem may emerge from the unit system between the HEC-RAS and that used in GIS. The GIS unit system must be re-projected according to the RAS unit.

Since most GIS inputs such as DEM, TIN and field cross sections are in metric unit it must be projected to the same unit. In the figure 3-20, the last two cross sections bank points are away from the channel bank lines, so that they require manual edition.

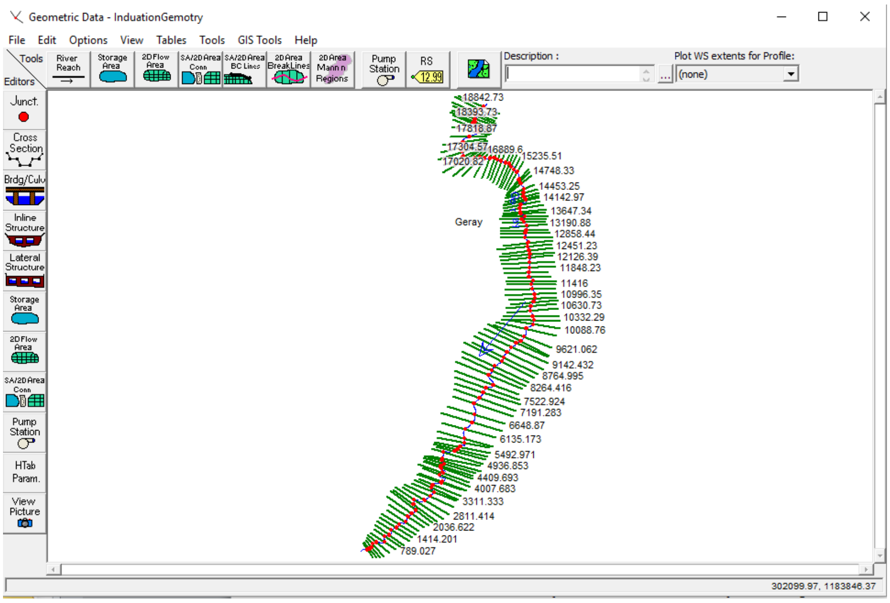


Figure 3-20: A cross section views in HEC-RAS

The geometric data window edits not only the river sections but also structures associated with the river system. This structures may be; bridges/culverts, deck/roadway, weir structures, levees, dykes etc. These structures are also digitized and geo-referenced in GIS and exported to HEC-RAS for further editing.

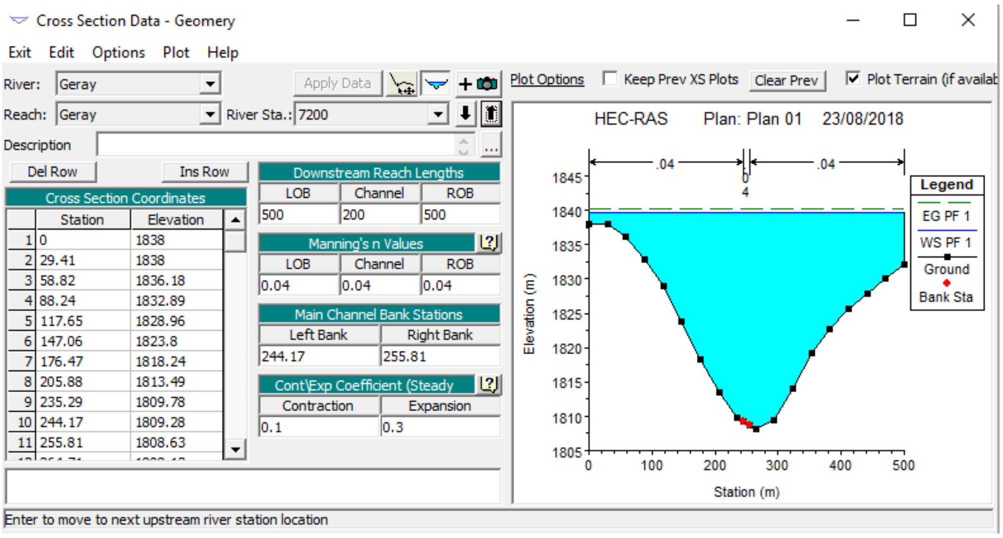


Figure 3-21: Cross section of river at station 7200 of the Geray River

The structures such as bridges and culverts could not be extracted from the TIN. These structures were manually added to the model through the HEC-RAS interface. The available field information did not include every bridge or culvert along the stream network.

3.10.3. Entering Flow data and Boundary condition

The discharge values for different return periods can be entered either manually or connecting to the desired location (for this paper Geray River) on HEC-HMS by exporting to HEC-RAS using HEC-DSS.

Manning's n values were used in the model to define roughness for each cross section. The "n" values were assigned in two steps: The first step involved defining land-use characteristics for common areas throughout the watershed and flood plain. Each land-use characteristic was given n-value based on published values for similar conditions (Chow, 1988)and on engineering judgment and experience.

Once the land-use was defined for the entire watershed, the representative n-values were assigned to the portion of each cross section that intersects the respective land-use area. These n-values were then exported to the HEC-RAS model using HEC-GeoRAS. For the study area the typical manning's coefficient is determined by using field survey photos and compared it with the standard "n" values of different land use.

Table 5: Manning's Values for Different Land Uses **(Chow, 1988)**

Types of channel and Description	Manning's Roughness (n) Values		
	Minimum	**Normal**	**Maximum**
Natural Streams			
1. Main channels			
1.1.Clean ,straight ,full ,no rifts or deep pools	0.025	0.030	0.033
1.2.Same as above ,but more stones and weeds	0.030	0.035	0.040
1.3.Clean ,winding ,some pools and shoals	0.033	0.040	0.045
1.4.Same as above ,but some weeds and stones	0.035	0.045	0.050
1.5.Same as above ,lower stage ,more ineffective slopes and sections	0.040	0.048	0.055
1.6.Same as 1.4 but more stones	0.045	0.050	0.060
1.7.Sluggish reaches ,weedy ,deep pools	0.050	0.070	0.080
1.8.Very weedy reaches ,deep pools or flood ways with heavy stands of timber and brush	0.070	0.100	0.150
2. Flood plains			
2.1.Pasture no brush			
2.1.1. Short grass	0.025	0.030	0.035
2.1.2. High grass	0.030	0.035	0.050
2.2.Cultivated areas			
2.2.1. No crop	0.020	0.030	0.040
2.2.2. Mature row crops	0.025	0.035	0.045
2.2.3. Mature field crops	**0.030**	**0.040**	**0.050**
2.3.Brush			
2.3.1. Scattered brush ,heavy weeds	0.035	0.050	0.070
2.3.2. Light brush and trees ,in winter	0.035	0.050	0.060
2.3.3. Light brush and trees ,in summer	0.040	0.060	0.080
2.3.4. Medium to dense brush, in winter	0.045	0.070	0.110
2.3.5. Medium to dense brush, in summer	0.070	0.100	0.160
2.4. Trees			

2.4.1. Cleared land with tree stumps ,no sprouts	0.030	0.040	0.050
2.4.2. Same as above ,but heavy sprouts	0.050	0.060	0.080
2.4.3. Heavy stands of timber ,few down trees ,little under growth ,flow below branches	0.080	0.100	0.120
2.4.4. Same as above , but with flow into branches	0.100	0.120	0.160
2.4.5. Dense willows, ,straight ,straight	0.110	0.150	0.200
3. Mountain streams ,no vegetation in channel banks usually steep ,with trees and brush on banks submerged			
3.1.Bottom : gravels ,cobbles ,and few boulders	0.030	0.040	0.050
3.2.Bottom : cobbles with large boulders	0.040	0.050	0.070

The roughness coefficients (Manning's coefficient) and boundary conditions were added to the model manually accordingly because the study area is characterized as: the main channels is clean, straight but more stones and weeds there for, mail channel manning roughness is 0.35 and the left and right overbank are selected based on their description of landuse and it is observed that it is under cultivated areas with matured filed crops and value for manning's roughness value is 0.04.

The model was run for subcritical flow regime conditions and steady flow water surface profile computations. The iterative solution of the energy equation, using the standard step method, solved the steady flow, while Manning's equation and contraction/expansion coefficients determined head losses.

Before applying the computation process the model must be set up for boundary condition. There are various methods of boundary condition used. The method used in this paper is the Normal depth at the both ends of the reaches which was determined by using the river profile in HEC-GeoRAS output.

Finally the plan must be established for each model simulation. The plan has a user specified description and application.

3.10.4. Calibration of HEC-RAS for Manning's Roughness Coefficient 'n'

The calibration of hydrodynamic model includes the choice of an appropriate value of Manning's 'n' such that simulated from the HEC-RAS model should be close to the observed stages along the physical model of the river. The 'n' value with least deviation in simulated and observed stages was considered as the optimal value for that discharge.

The software used for calibration of sensitive parameters in HEC-RAS is known as; Automating Hydraulic Analysis (AHYDRA) which is a freeware application that automates features from hydraulic software such as HEC-RAS. It is intended to ease the task of sensitivity and uncertainty analysis in water related studies.

The basic data needed to calculate hydraulic profiles of a channel are the discharge, channel geometry, water elevation at a control section and channel roughness. Discharge is a given data and the channel geometry is obtained by measurements. Usually the water elevation at control section (boundary condition) and channel roughness are unknown and have to be estimated by indirect ways.

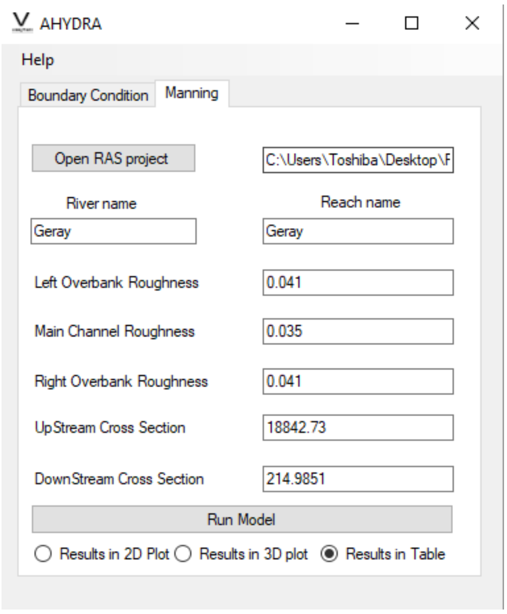


Figure 3-22: Calibration of manning's roughness coefficient using AHYDRA

3.10.5. Exporting HEC-RAS Results and Post-RAS processing

Once HEC-RAS computed values are completed with no errors, the next step is exporting the output to ArcGIS for post-RAS processing. Post-RAS processing is the one which uses HEC-RAS output for floodplain inundation mapping and delineation.

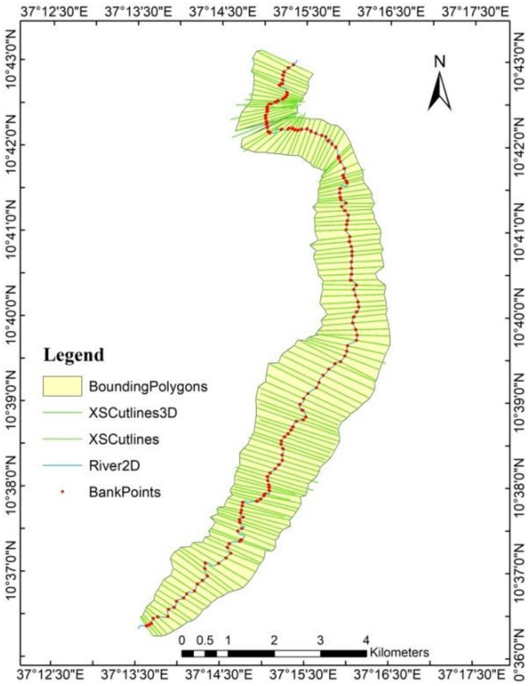


Figure 3-23: Bounding polygon for the water surface TIN generation

3.11. Floodplain Delineation

Areas inundated by flooding occur wherever the elevation of the floodwater exceeds that of the land. To delineate these areas, we will create surface models of the floodwater and land surface, and then compare the elevations. Let's start with the floodwater model. HEC-RAS represents the floodplain as a computed water surface elevation at each cross-section.

During the data import step, these elevations were brought into ArcGIS, along with the distance from the stream centreline to the left and right floodplain boundaries. Hence, two things are known about the floodplain at each cross-section: water surface elevation and width on each side of the centreline.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1. Data Consistency and Homogeneity Results

After filling missing data of the precipitation using Normal Ratio Method which gives weighted mean with biasing the weights on mean annual precipitation at each gauge, Data consistency and homogeneity will be checked and the results is postulated.

Here accumulated annual values at the station in question are plotted against those of nearby reliable station or group of stations. An abrupt deviation in the slope of the Double-Mass Curve plot suggest some change not related to climatic variables, and adjustment should be made to the data on the basis of the ratio of the slopes of the two segments.

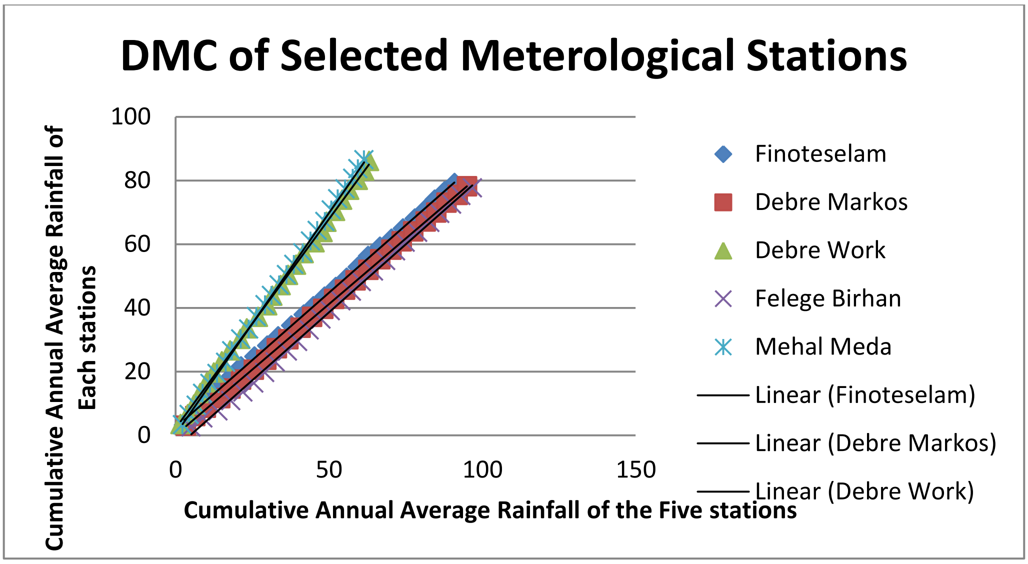


Figure 4-1: DMC of four stations selected with high data consistency

The homogeneity graph is plotted to compare the stations with each other as shown in figure below (nearest stations for Geray River). The figures almost have the same pattern and bimodal. Therefore, from the selected stations ones those were found to be homogenous with the selected meteorological stations are Debre Work and Felege Birhan and were used to fill missing data of Finote Selam Meteorological stations.

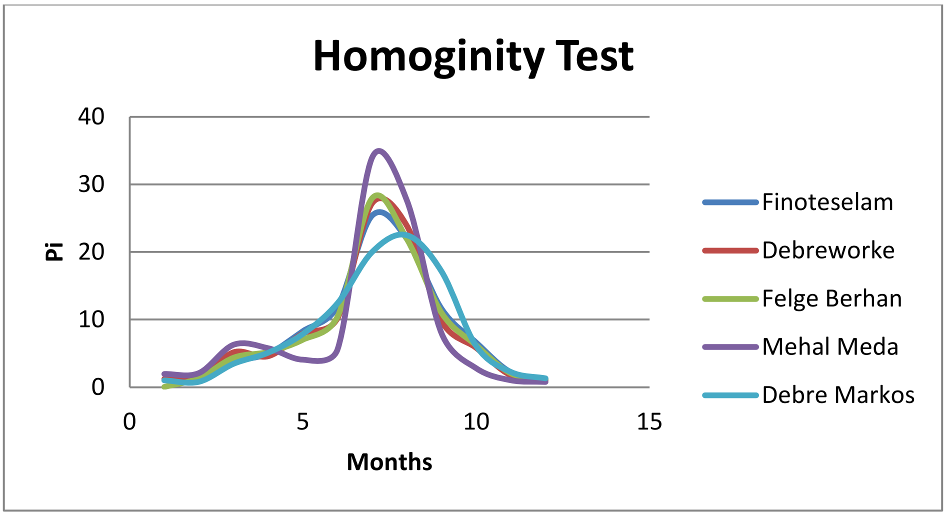
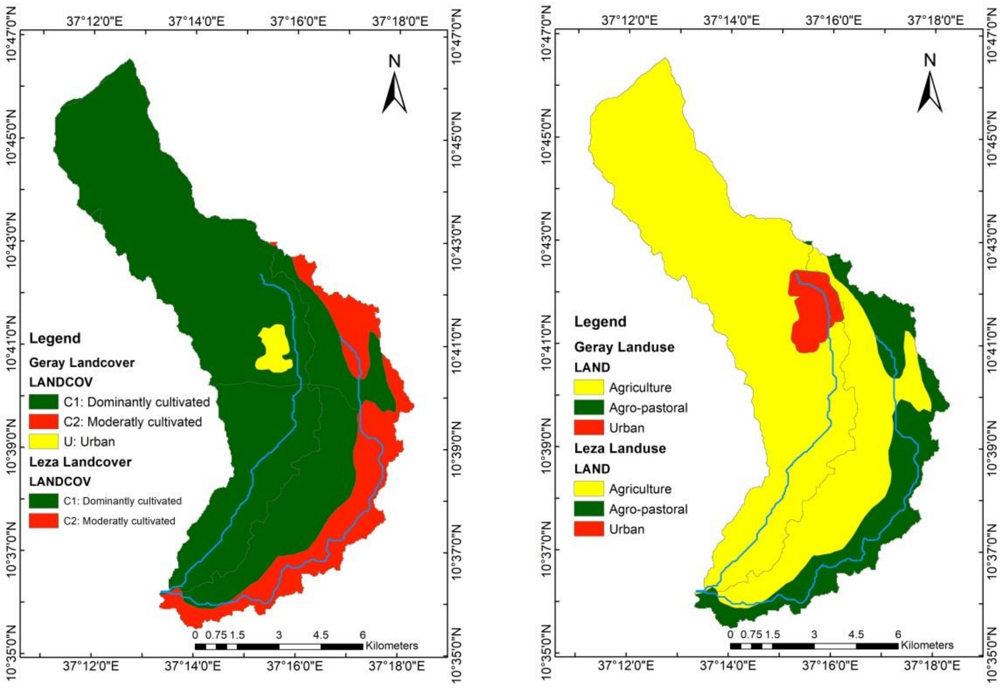


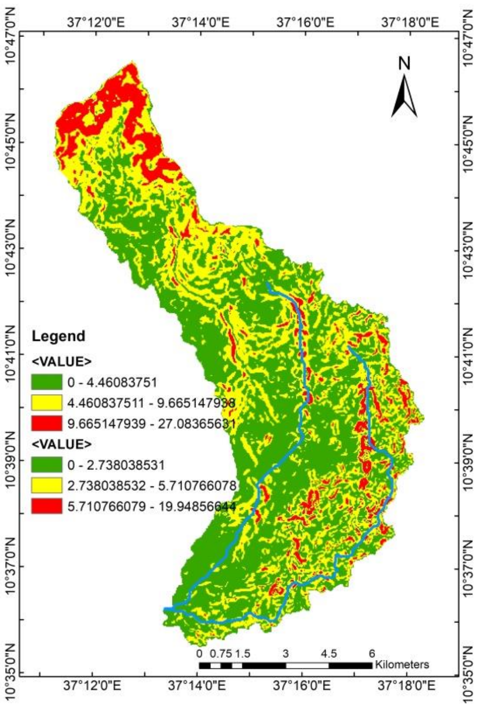
Figure 4-2: Homogeneity Test for areal rainfall stations

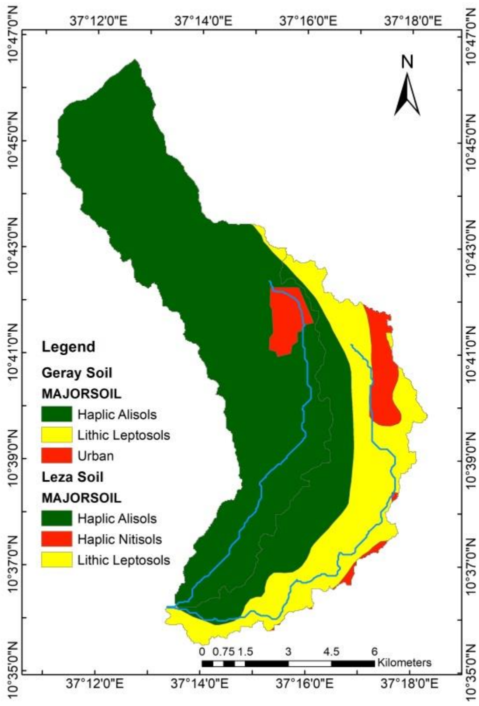
4.2. Flow Data Results

Geray Rivers is not gauged at the confluence point. The site of water resource development in any of the uses can be at or ungagged site. If gauged data with sufficient record length is available then such data is used. The neighbouring catchment to Geray River is Leza River. Therefore, by checking the similarity of both catchments by their land cover, landuse, soil type and slope, the area ratio method was executed as follows.



A B





C D

Figure 4-3: Catchment similarity checking between Geray and Leza

Using: A) landcover B) landuse C) slope D) soil types

If $A_{ungauged}$the is within 20% of the A_{gagged} ($0.8 \leq \frac{A_{ungauged}}{A_{gauged}} \leq 1.2$) then n=1 to be used. The estimated discharge at the site will be within 10% of actual discharge (Awlachew, 2000).

$$\frac{A_{Ungaguged}}{A_{Gauged}} = \frac{118.4969}{123.5695} = 0.96$$

Therefore, $\frac{A_{Ungaguged}}{A_{Gauged}}$ of this site of interest is 0.96 in which n is 1 and the area ratio formula for Geray River is:

$$\boldsymbol{Q_{unguaged} = 0.96 \times Q_{guaged}} \text{..............................} (27)$$

Using Area Ratio method the above formula was developed and used to develop flow data for Geray River based on catchment similarity with Leza River.

4.3. Data Filling and Consistency

Before employing flow data for the ungauged river of Geray, there need to be data filling of missing flow data of Leza river using correlation and developing regression equation for the river.

The correlation equations used for Leza gauging station in terms of neighbouring gauging station using one year streamflow was done, and Leza River with Birr River which shows good correlation is expressed below.

Table 6: Correlation between Geray and other nearby Rivers using SPSS

Correlations Between Rivers

		Leza	Birr	Gudela
Leza	Pearson Correlation	1	**0.758****	0.645**
	Sig. (2-tailed)		.000	0.000
	N	366	366	366
Birr	Pearson Correlation	**0.758****	1	.574**
	Sig. (2-tailed)	0.000		.000
	N	366	366	366
Gudela	Pearson Correlation	0.645**	0.574**	1
	Sig. (2-tailed)	.000	.000	
	N	366	366	366

**. Correlation is significant at the 0.01 level (2-tailed).

Table 7: Correlation between Leza and other nearby rivers using Excel

	Leza	*Birr*	*Gudela*
Leza	1	**0.758306**	0.644644
Birr	**0.758306**	1	0.574304
Gudela	0.644644	0.574304	1

Regression equation developed between Leza River as a response variable and Birr river as explanatory variable used to fill missing flow data.

$$\boldsymbol{Y = 0.30947598 + X0.01985625} \text{.................................} \quad (28)$$

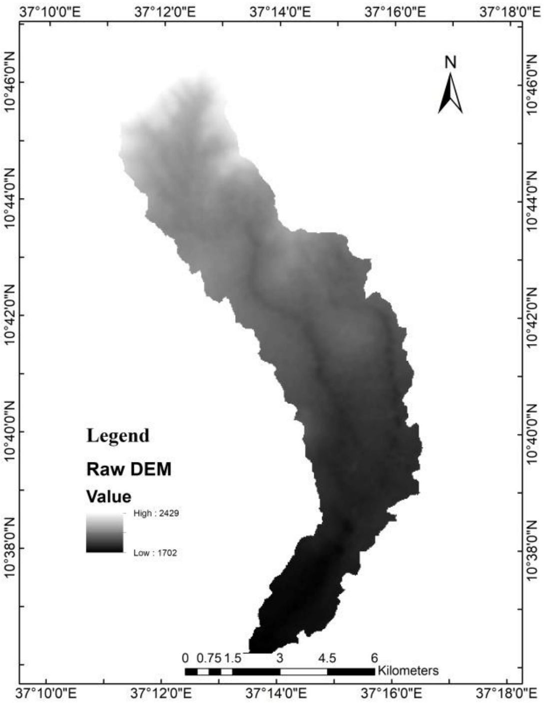
Where: - Y: - is missed flow value at Leza River gage

X: - is flow value at Birr river gauge

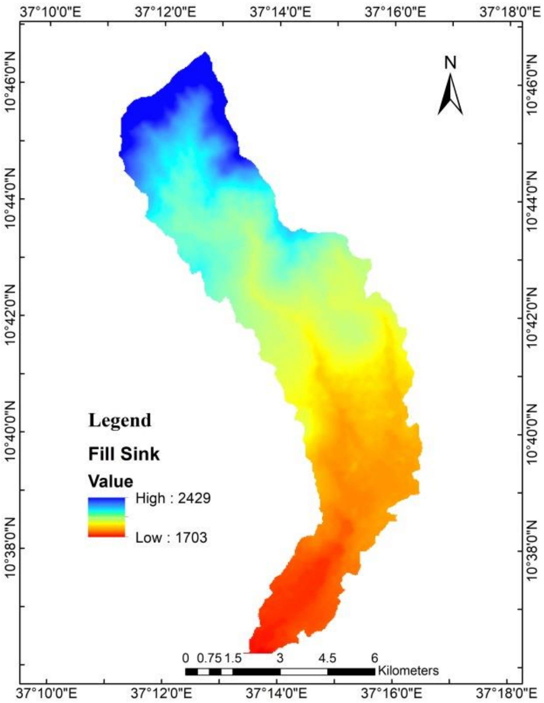
4.4. Terrain Processing Using Arc-Hydro Results

All the steps in the Arc-Hydro Terrain Preprocessing menu were performed in sequential order, from top to bottom. The procedure followed for terrain processing using Arc-Hydro is explained under using 30x30 DEM extracted for the respective sub basins and river feature class of the study area. For simplicity the main steps undertaken by Arc-Hydro processing are: DEM reconditioning, Fill sinks, Flow direction, Flow accumulation, Stream definition, Stream segmentation, Catchment grid delineation, Catchment polygon processing, Drainage line processing, Drainage point processing, longest flow path for the catchment and Slope determination.

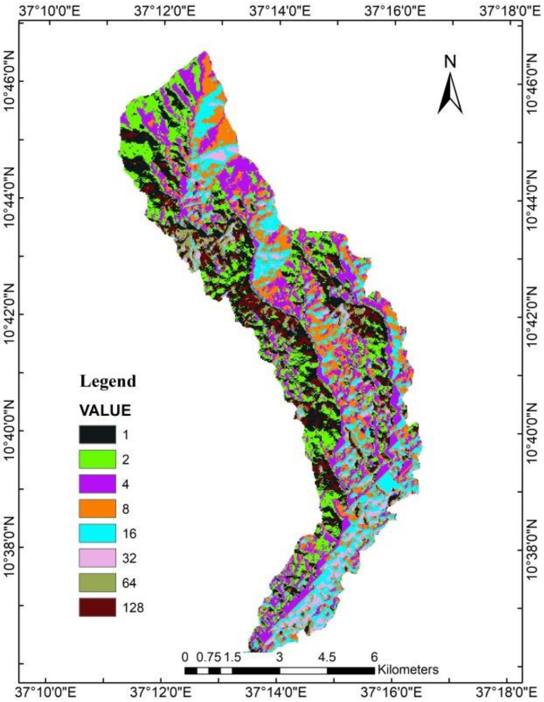
The terrain processing result for the sub basin is shown below in Figure 4-3.



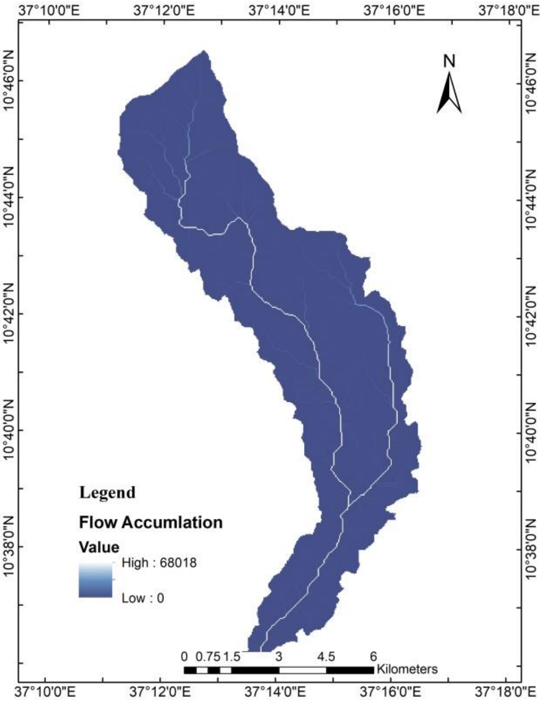
A



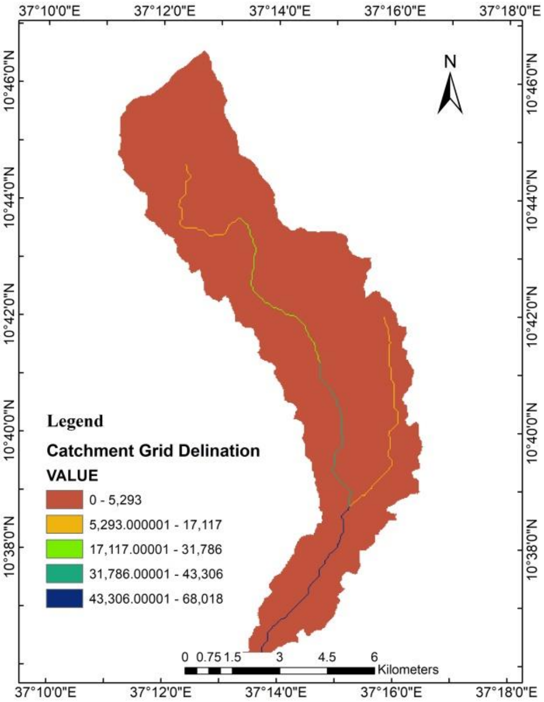
B


Legend
VALUE
1
2
4
8
16
32
64
128
0 0.75 1.5 3 4.5 6 Kilometers

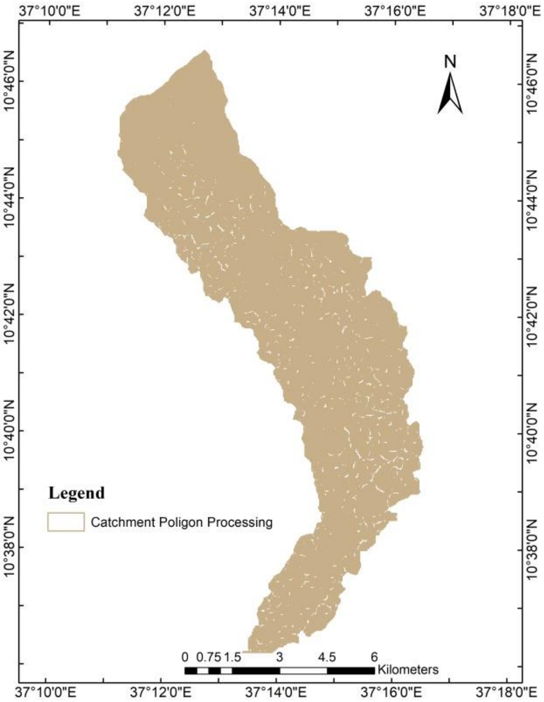
C


Legend
Flow Accumlation
Value
High : 68018
Low : 0
0 0.75 1.5 3 4.5 6 Kilometers

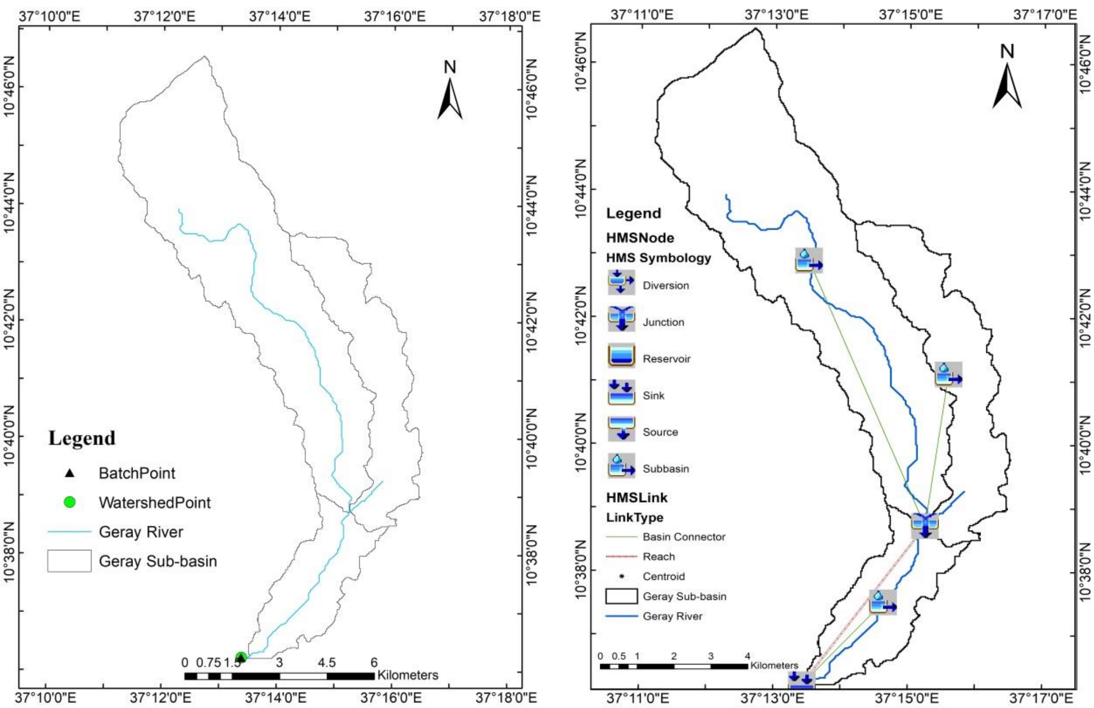
D


Legend
Catchment Grid Delination
VALUE
0 - 5,293
5,293.000001 - 17,117
17,117.00001 - 31,786
31,786.00001 - 43,306
43,306.00001 - 68,018
0 0.75 1.5 3 4.5 6 Kilometers

E


Legend
Catchment Poligon Processing
0 0.75 1.5 3 4.5 6 Kilometers

F



G H

Figure 4-4: Terrain processing for Geray sub basin using Arc hydro:

A) Raw DEM B) Fill sink C) Flow direction D) Flow accumulation E) Catchment grid delineation F) Catchment polygon processing G) Batch point watershed delineation at the outlet of Geray River H) HMS Legend and Schematic.

The output from terrain processing in Arc Hydro is not only delineation and schematic for the catchment but also extraction of basin characteristics from physical properties of the catchment. Among the basin characteristics soil and land use are the major ones. According to the output of the model the following parameters are generated.

Table 8: Catchment characteristic parameter extracted

Component	Parameter	Unit	Value
Sub-basin 1	CN		82.995
	I_a	mm	10.41
	A	Km^2	41.470
	Basin Slope	m/m	10.17
Sub-basin 2	CN		83.053
	I_a	mm	10.366

	A	Km^2	14.759
	Basin Slope	m/m	7.42
Sub-basin 3	CN		82.978
	I_a	mm	10.42
	A	Km^2	9.49
	Basin Slope	m/m	5.31

4.5. Model Calibration and Validation of HEC-HMS Results

A total of 20 years historical data from 1990 to 2015 is used, calibration (1990- 1999) and validation (2001-2010) for the selected watersheds of the sub basins. Manual and automatic calibration was used for optimization of observed and simulated flow data using initial parameter from watershed characteristics. Calibration was done by taking initial parameters generated from HEC-GeoHMS and ArcHydro for the catchment. With the initial parameters, the calibration was then processed until the simulated value resembles the observed data.

Table 9: Optimized parameters of HEC-HMS for Geray catchment

Component	Parameter	Unit	Initial	Optimized
Subbasin-1	SCS Curve Number - Curve Number		82.995	84.076
Subbasin-1	SCS Curve Number - Initial Abstraction	MM	10.41	9.7978
Subbasin-1	SCS Unit Hydrograph - Lag Time	MIN	153.69	153.69
Subbasin-2	SCS Curve Number - Curve Number		83.053	84.136
Subbasin-2	SCS Curve Number - Initial Abstraction	MM	10.366	3.0714
Subbasin-2	SCS Unit Hydrograph - Lag Time	MIN	118.01	118.01
Subbasin-3	SCS Curve Number - Curve Number		82.978	84.050
Subbasin-3	SCS Curve Number - Initial Abstraction	MM	10.42	23.561
Subbasin-3	SCS Unit Hydrograph - Lag Time	MIN	94.560	94.560
Reach-1	Muskingum – K	HR	79.807	73.611
Reach-1	Muskingum – X		0.0025	0.0023530

Flow hydrographs for the observed and simulated flows at Geray gaging station is presented in figure 4-5.

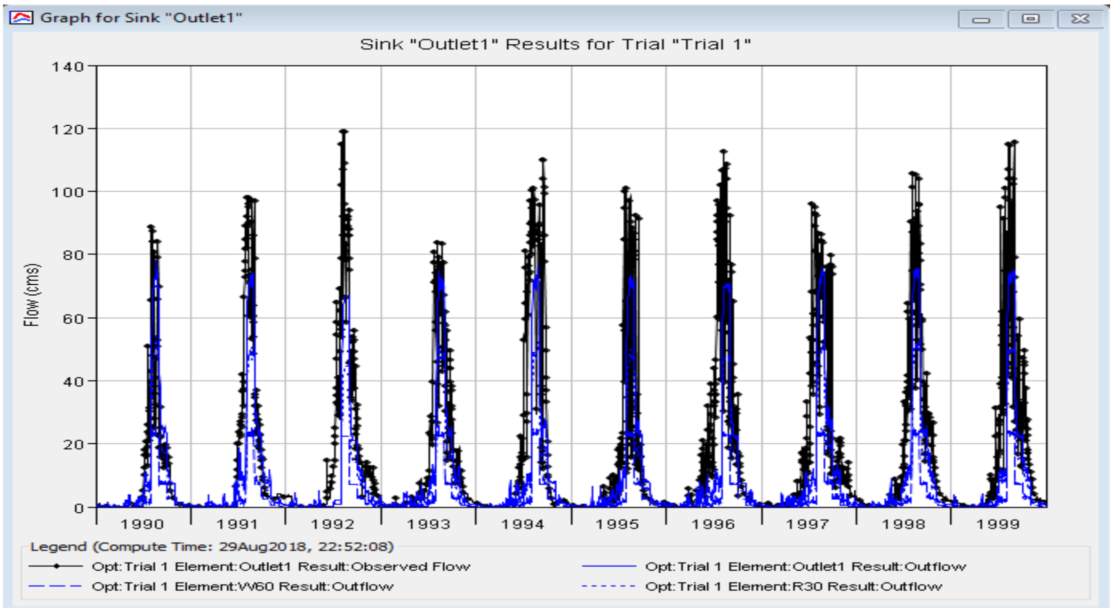


Figure 4-5: Calibration of HEC-HMS Output

For these particular paper efficiency evaluation criteria parameters must resemble each other. For the Geray catchment case the ENS has a value of 0.565 and R^2=0.589. Therefore, the values determined from calibration of HEC-HMS model are acceptable.

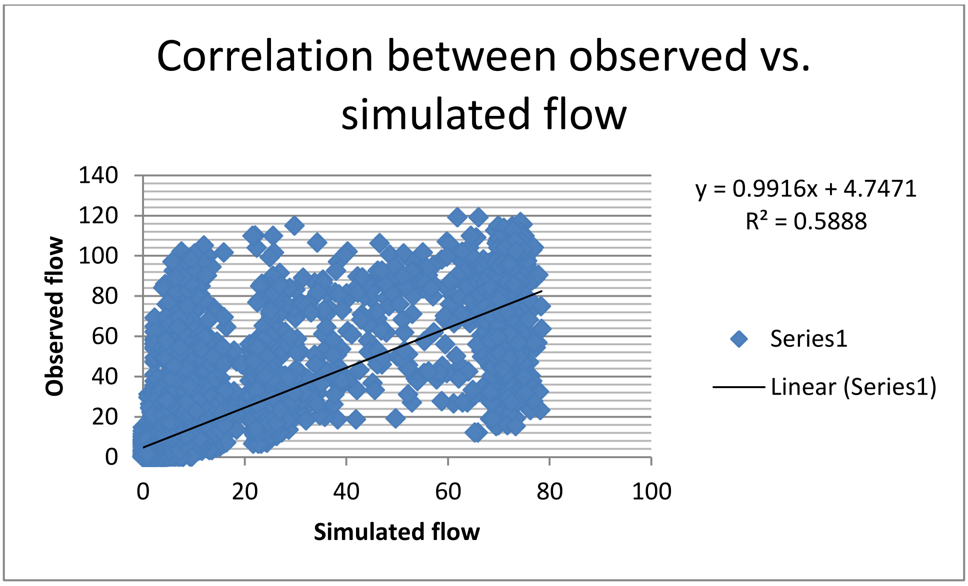


Figure 4-6: Correlation between observed vs. simulated flow

To validate the model data of 10 years (2000-2009) was used by applying the optimized parameters in the calibration process. And the output of the validation process has a value of ENS 0.547 and an R^2 of 0.582. This result implies the validation process is ok to move on the next process.

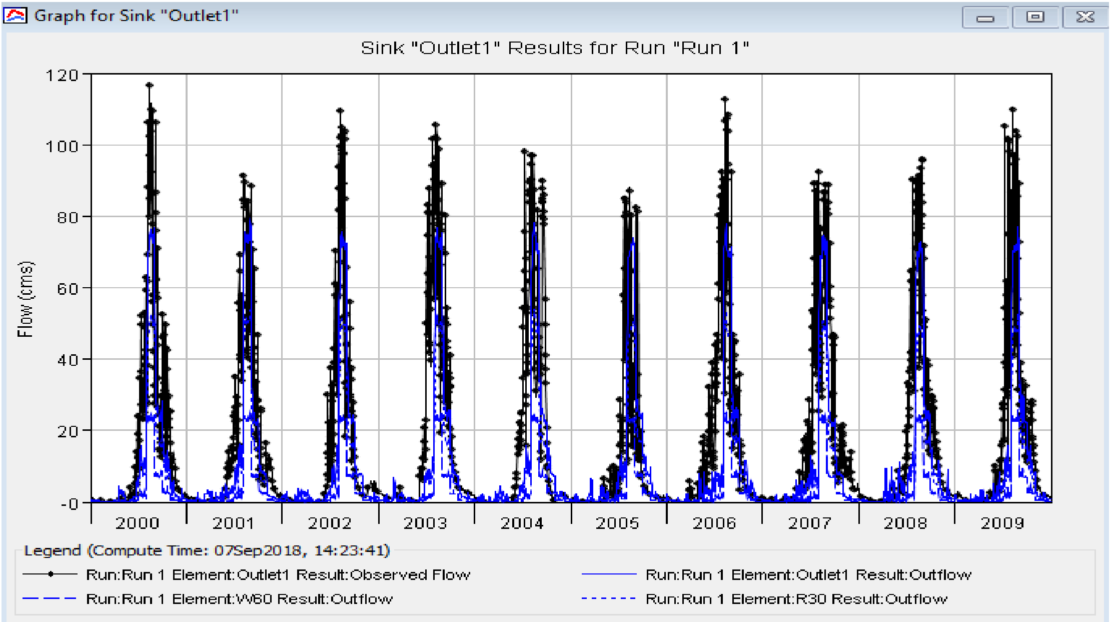


Figure 4-7: Validation of HEC-HMS Output

4.6. Output of HEC-HMS by Frequency Storm

The model has a capability to produce and generate values for different flow conditions (return periods). Given the input parameters from HEC-HMS, the flow values are found accordingly. From the result table minimum peak flow for the Geray River is occurred for 2 years return period for 24 hour storm duration and the maximum obtained with 100 years frequency storm for the same duration. The value being 109.1m^3/s and 362.7m^3/s for 2 years and 100 years frequency respectively. Peak flow the rest of the return periods is in table 10.

Table 10: Determination of Peak Discharge Using HEC-HMS Frequency Method

No.	Return Periods	Peak Flow (m^3/sec)
1	2	109.1
2	10	214.9
3	25	274.4
4	50	318.4
5	100	362.7

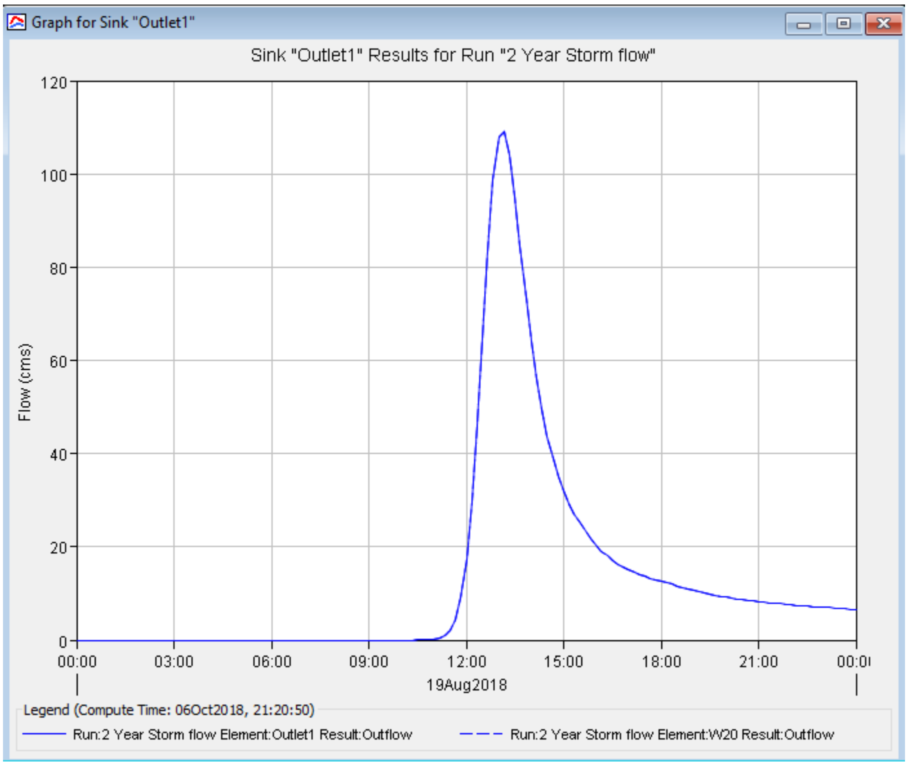


Figure 4-8: 2 years flow hydrograph of Geray River

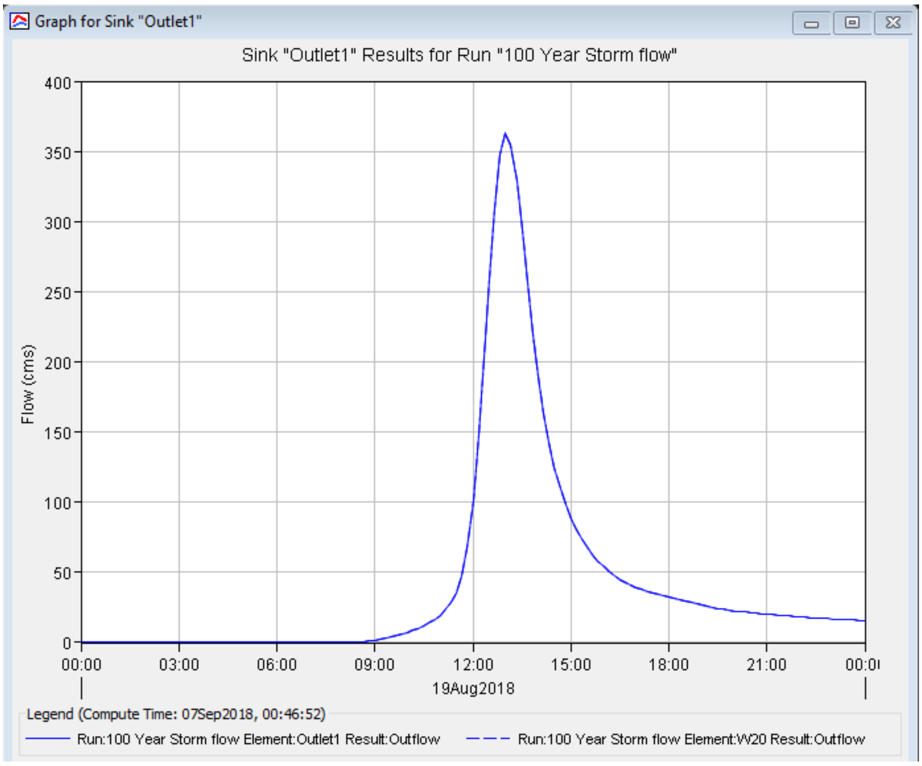


Figure 4-9: 100 years frequency streamflow hydrograph of Geray River

4.7. Flood Frequency Analysis Results

Finally the HEC-HMS model result is compared with the frequency analysis results considering different techniques. The methods applied in this paper are selected based on their Goodness of fit on EasyFit software. According to the software's output Extreme value method was the number one goodness fit, Log-Pearson, Normal, and Lognormal following respectively.

Therefore, using the formulas to determine magnitude of the hydrological event, output values of each different distribution method were compared with the outcome of HEC-HMS values for each return period.

Table 11: Comparison of flow values (frequency analysis and the HEC-HMS)

Distribution Method	2	10	25	50	100
EV Type 1	116.56	177.29	207.39	229.95	252.35
Log-Pearson III	121.11	165.76	182.26	192.69	201.93
Log-normal	164.13	169.31	193.56	210.67	227.17
Normal	171.42	175.94	195.43	207.77	218.75
HEC-HMS	109.1	214.9	274.4	318.4	362.7

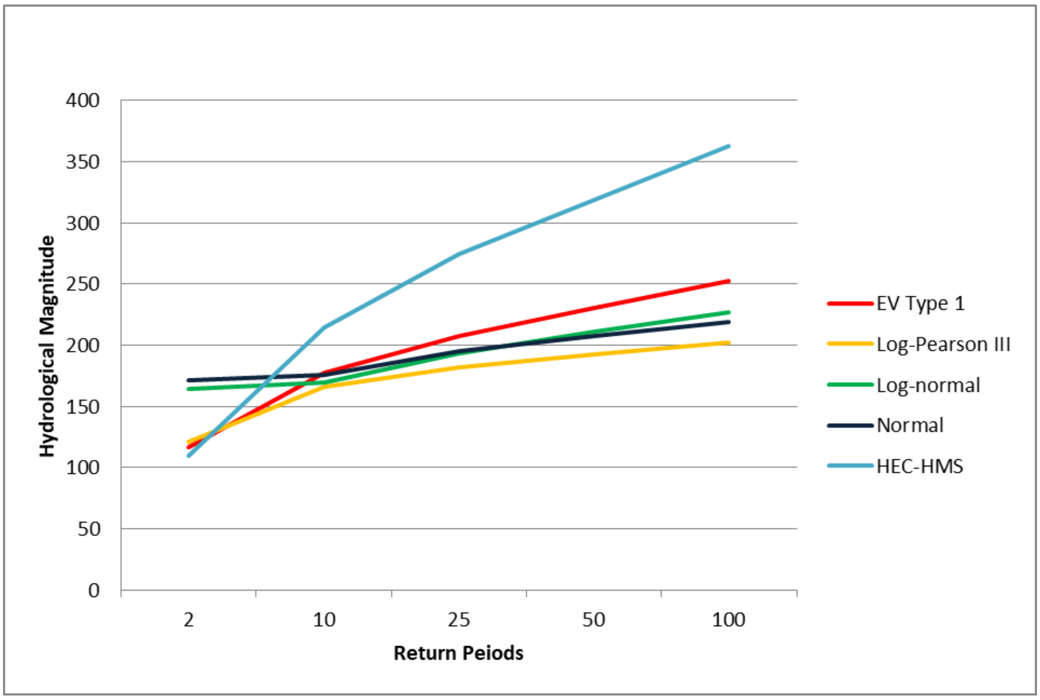


Figure 4-10: Comparison of the flow values of the Geray River

4.8. Calibration of HEC-RAS for Manning's Roughness Coefficient 'n'

The calibration of HEC-RAS model includes the choice of an appropriate value of Manning's 'n' such that accordingly to the land use of the study area the selected manning's roughness coefficient was 0.041 for left and right over banks and 0.035 for main channel. After inserting all the necessary data to AHYDRA software; results was tabulated in profile output table for different manning roughness.

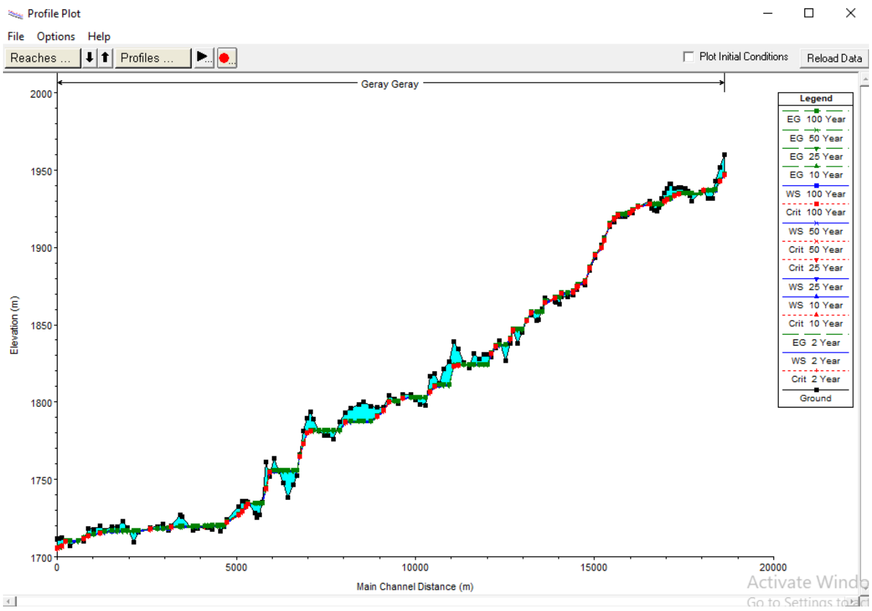


Figure 4-11: 2D model for Manning's roughness calibration

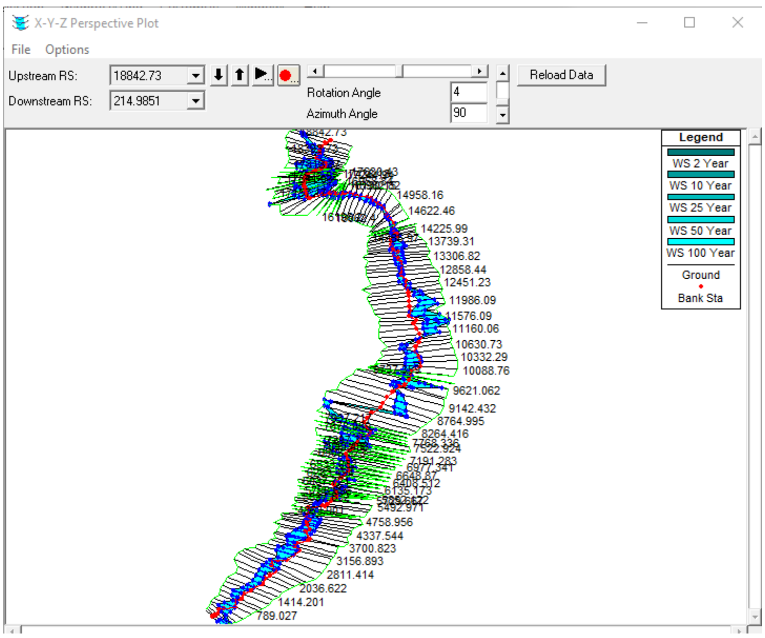


Figure 4-12: 3D model of manning's roughness calibration

4.9. HEC-RAS Output

HEC-RAS requires flow and topographic data as channel and floodplain cross section. Given this two sets of data in appropriate form the resulting model efficiency is high. The model gives the floodplain water surface profile in 2D view.

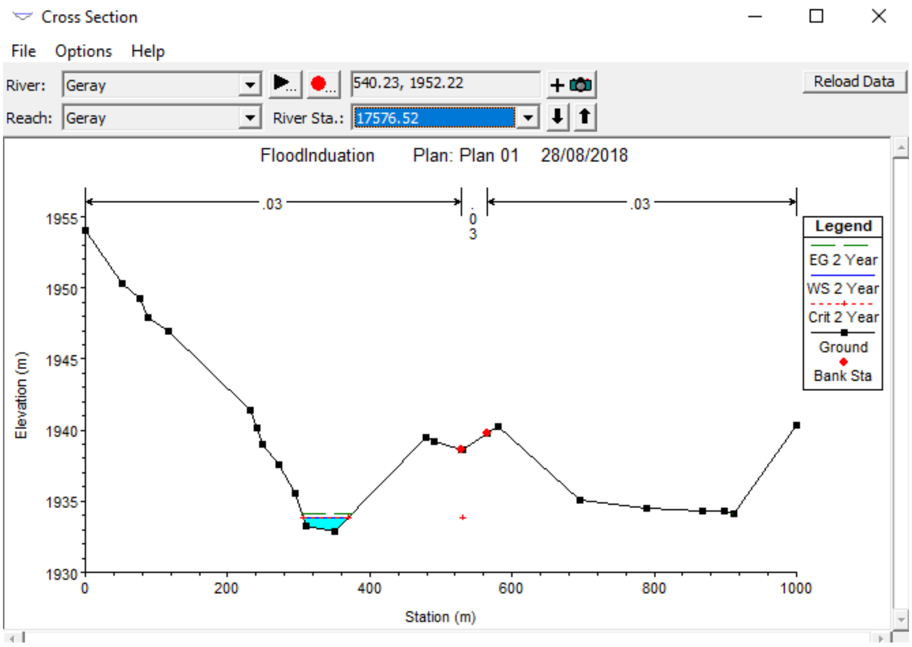


Figure 4-13: Cross section of River station 17576.52 for 2 years return period

In the output cross section view, the river channel is seen as v-shaped. In real case it shouldn't be like that. This is because of the high stretch of the flood plain with respect to the channel width. One can simply observe the fact.

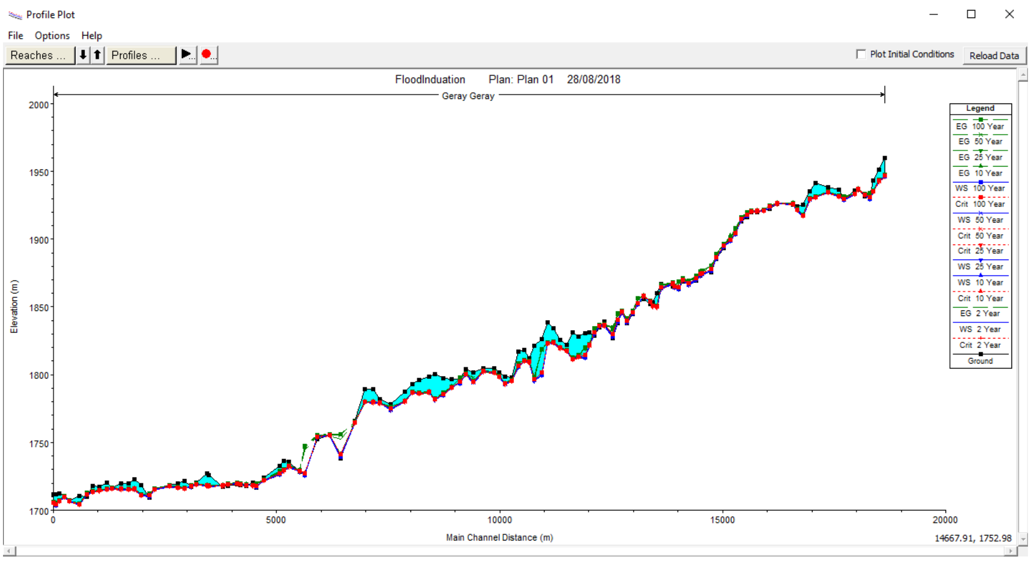


Figure 4-14: General profile plot of the reach for 100 years storm

Other application of HEC-RAS is providing the 2D river water profile to ArcGIS to display the floodplain in 3D. The floodplain mapping and finally delineated output is the one which uses the RAS output in the form of the river profile.

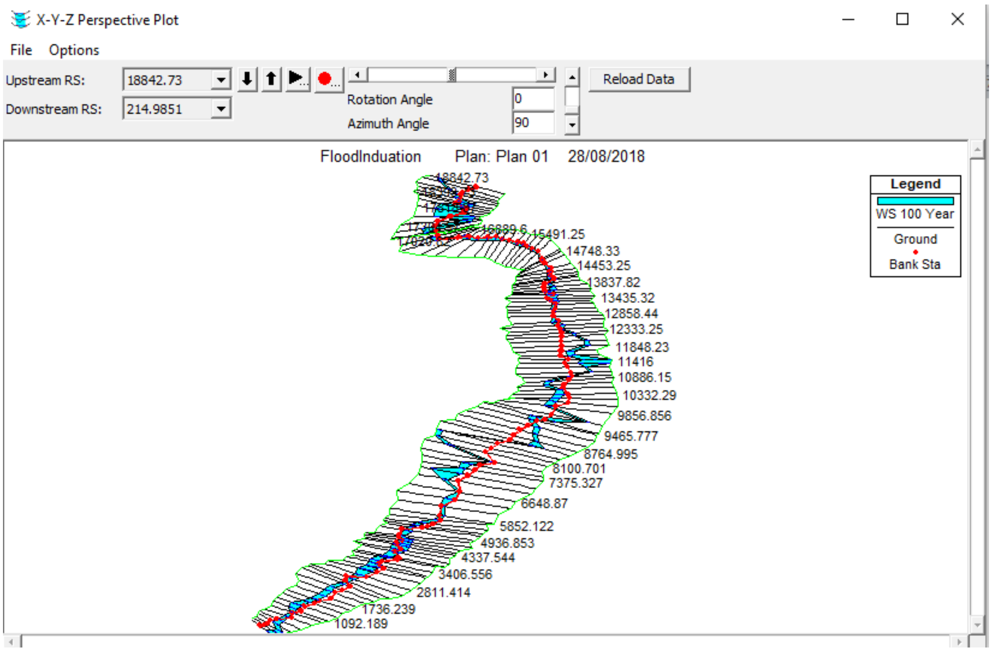


Figure 4-15: 3D view of the floodplain in HEC-RAS 100 years storm

Finally, the output table for the model is given for each station consisting of different parameters. The parameters can be changed during calibration. The HEC-RAS is calibrated for the cross section parameters only. This is because the flow data has already passed calibration and validation processes. One of the difficult part or shortcoming of this model is its complexity during calibration. The availability and accuracy of cross section data may reduce the burden.

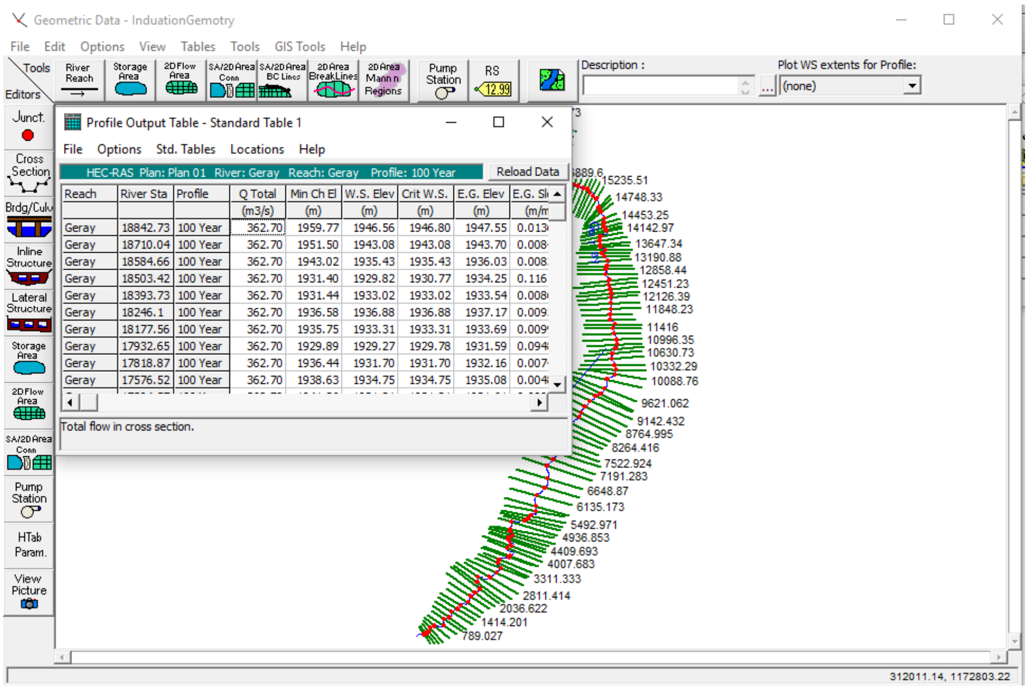


Figure 4-16: RAS profile output table

4.10. Flooding on Jabi Tehnan Woreda

With the bounding polygon created (figure 5-16), water surface TIN is created from the given profiles and underlying DTM/TIN. The water surface TIN consequently gives rise to floodplain delineation.

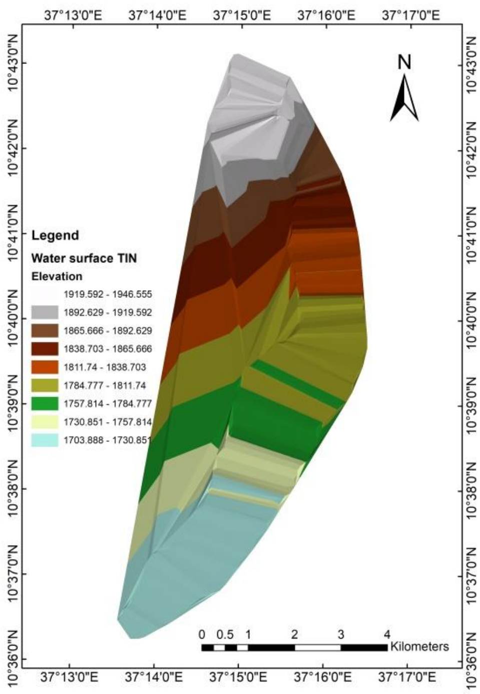


Figure 4-17: Water surface TIN generated from bounding polygon

With the bounding polygon created (figure above), water surface TIN is created from the given profiles and underlying DTM/TIN. The water surface TIN consequently gives rise to flood plain delineation

ArcGIS with an extension of HEC-GeoRAS then delineates flood plain for different flow conditions. In this paper, there are five storm flows considered (2, 10, 25, 50 and 100 years). Each storm flow has different flood plain depth, extent and area.

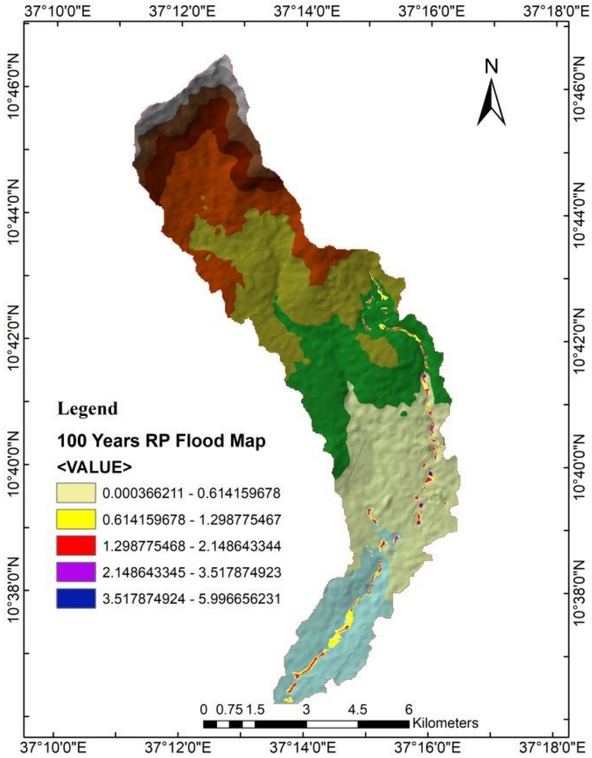


Figure 4-18: 100 years flood map and depth for the study area

From the above figure for 100 years storm event, it can be seen that the depth of the flood ranges from 0m-6m. The flood extent also stretches to about 2km having 1km from each side.

The 2 years flood as shown in figure 4-18 has also a flood depth of 5.08m and extent area. The maximum area inundated is 0.87km^2. Most flooding extents are severing with 100 years and 50 years storm events. This is due to the amount of the flood flow.

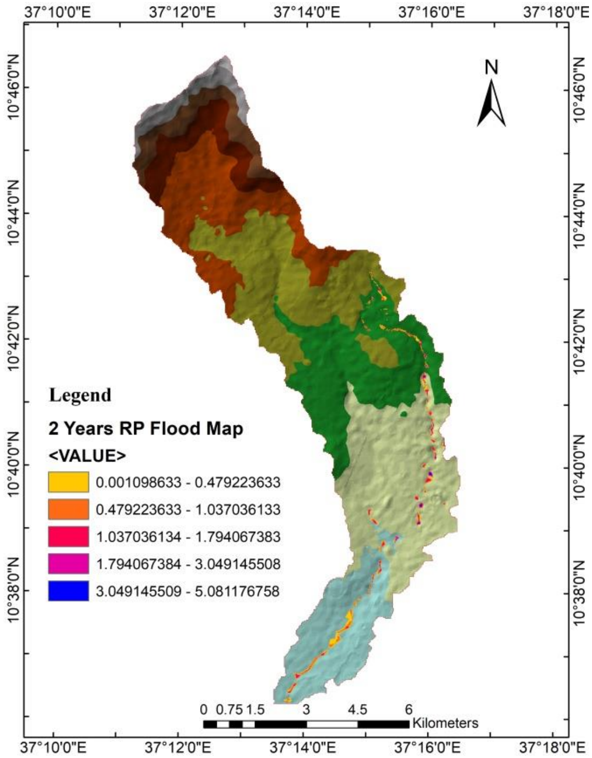


Figure 4-19: 2 years flood map and depth for the study area

4.11. Flood Vulnerability and Damage Analysis

4.11.1. Flood Vulnerability Analysis

Vulnerability is the degree of loss of land to flooding at risk resulting from the occurrence of a natural phenomenon of a given magnitude. It is expressed on a scale from 0% (no damage) to 100% (total loss).

The vulnerability maps for the flood areas were prepared by intersecting the land use map of the floodplains generated with the flood area polygon for each of the flood event being modelled.

This depicts the vulnerability aspect of the flood risk in the particular area in terms of the presence or the absence of flooding of a particular return period as a binary model.

Most of the areas around the floodplain are agricultural land with less proportion of urban and agro-pastoral area of Finote Selam. 83.33% of the flood inundated areas are covered by agricultural lands and the remaining 14.49% is covered by urban areas of Finote Selam and the rest 2.17% is covered by Agro-pastoral.

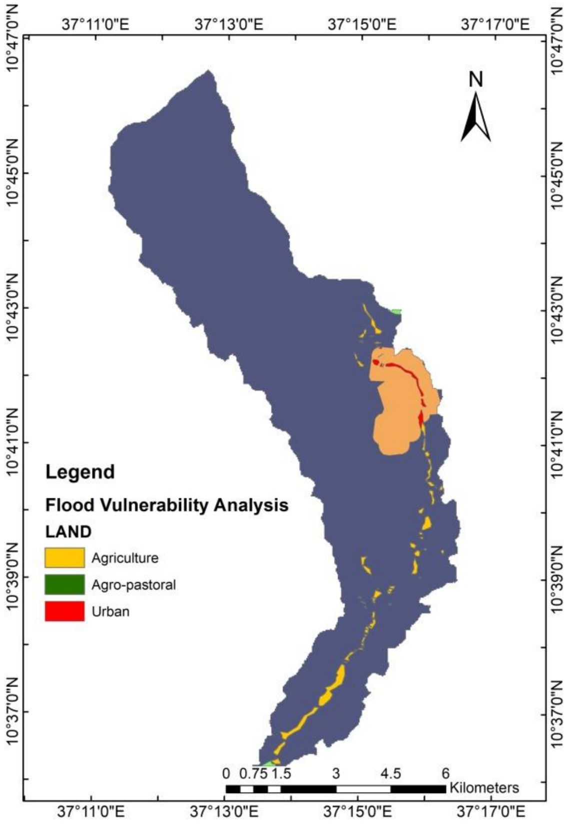


Figure 4-20: Vulnerability map of the study area

Therefore, according to the flood damage and vulnerability analysis protection for the agricultural landuse should be

4.11.2. Flood Damage

The actual amount of flood damage of a specific flood event depends on the vulnerability of the affected socio-economic and ecological systems, i.e., broadly defined, on their potential to be harmed by a hazardous event (Cutter, 1996).

Damage due to flooding depends on several factors, such as water depth, duration of flooding, flow velocity, sediment concentration and pollution. This study will focus only in damages due to floodwater depth.

A conventional approach for the estimation of direct flood damage to Agricultural land in Geray Catchment is using the method of depth-damage functions. Using this depth-damage method the estimated damage to the agricultural land use is 20.65 Km^2.

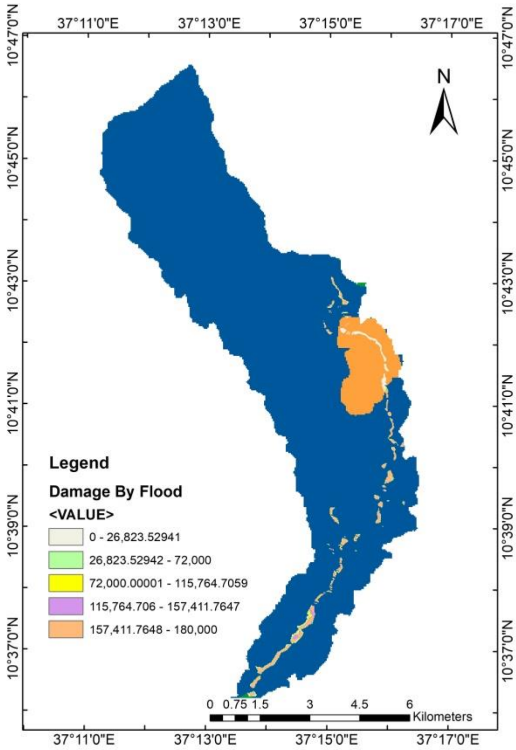


Figure 4-21: Flood damage of the study area

4.12. Discussions

The applications of hydraulic model and GIS for floodplain analysis have been limited in countries like Ethiopia, where the availability of the river geometric, topographic and hydrological data are also very limited. The situation of river flooding in Ethiopia is also completely different, as there is much higher variation in the river flows and rivers are completely unregulated. There are very few flood control structures dykes at river banks and boundary lines which are not clearly defined.

Hence, the floodplain analysis and modeling are subject to number of new sets of constraints. This study presents an approach of conducting a similar study, within these constraints.

A. HEC-RAS and ArcGIS were the primary software packages used for this analysis. HEC-GeoRAS extension facilitated the exchange of data between ArcGIS and HEC-RAS.

B. Most hydrologic model using HEC-HMS analysis is conducted using personal judgment of parameter estimation. To overcome the gap in result variability, HEC-GeoHMS is a better means.
C. The spot elevations from field survey, contour line and good resolution DEM are used to prepare the digital terrain model of the study area so that it can represent the river channel and floodplains adequately.
D. The flood discharge of different return period is derived by different method. In this paper the result derived from model result of HEC-HMS is considered representative of the right flow value.
E. According to the model results, there is considerable flooding in the area even at flood discharge of 2-years frequency storm. This implies that the channel capacity is small to carry the flood water discharge.
F. The flood risk maps prepared indicate a high risk to the agricultural, agro-pastoral land and river with considerable water depth. These areas are the most flood prone areas in the river floodplains and need further considerations for flood protection.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Flooding around Jabi Tehnan Woreda causes a considerable damage to life and property. Large coverage of the area with cultivated land makes the problem hard. There was not past flood forecasting of the area, Therefore since the river accomplices to irrigation scheme at the downstream this paper can be useful to avoid upcoming damage due to such effect.

The main source of flooding in Jabi Tehnan flood plain is a result of flash flood originating from rainfall on the upper catchment of the Geray River catchment from Finote Selam highlands to the lower reach of the Setein Woreda floodplain. It is formed as a result of intensive showers, and steep slope of the areas topography.

This study presents a systematic approach in the preparation of flood map of vulnerability and risk with the application of steady flow models and ArcGIS. The major tools/models used in this method are one-dimensional numerical model HEC-RAS and ArcGIS for spatial data processing and HEC-GeoRAS for interfacing between HEC-RAS and ArcGIS.

A. The automated floodplain mapping and analysis using these tools provide more efficient, effective and standardized results and saves time and resources.
B. The presentation of results in GIS provide a new perspective to the modelled data and this approach can facilitate a transition from a flood hazard model based on the field investigation to a knowledge-based model that can be related to flood intensity.
C. The assessment of the vulnerability due to the flooding was made with regard to the land use pattern in the flood areas. The assessment of the flood area indicates that a large percentage (more than 88 %) of vulnerable area lies in flood plain area i.e. agricultural land followed by agro-pastoral and river comprising 14.49% and 2.17% respectively.
D. The study also made the assessment of flood hazards with relation to the return period of floods and their water depth. The relationship between the

flood area and discharge indicates that there is a medium rate of increase of the flood area with the increase in discharge. The examination of the flood water depth shows that most of the areas under flooding have water depth less than 1.5m with most of the depths range from 0-1.4m.

E. Risk map of the study area shows the area under agriculture is highly affected by even the 2-years flood which becomes higher by 100-years storm flood.

The 100 years return period peak flood discharge estimated using Computer Programs HEC-GeoHMS and HEC-HMS found to be 362.7m^3/sec and ERA's IDF curves for region A2 is used for flood analysis in the study area's plain. Flood affected areas are delineated for 100 years and 2 years return period peak flood discharge using two models HEC-GeoRAS and HEC-RAS one after another (i.e. first HEC-GeoRAS then HEC-RAS then back to HEC-GeoRAS). The left and right sides distance range of Geray River which are affected by the 100 years return period peak flood varies from place to place.

The total area affected by this flood is 1.29km^2 and the area affected by the 2years flood inundation of 5.08m is 0.87km^2.

5.2. Recommendations

5.2.1. Recommendation for Further Work

This study was conducted under major constraint of limited data availability. Therefore, the following recommendations are made for the further studies in the future.

1. Topographical Data: For modeling flows in overbanks, topographic data should be of high resolution and available enough so that the topography of the floodplains could be properly represented.
2. Flow data: The major hydrologic parameter without comparison to rainfall, flow data of long time duration is necessary for the calibration and validation of hydrologic model. Unavailability of hourly meteorological data should be addressed.
3. Use of new technology to generate TIN: TINs obtained using new technologies such as LIDAR (Light Detection and Ranging), which

improves the quality of the digital terrain representations is better if used for further study.

4. Up-to-date DEM should be adapted for high accuracy and high resolution (better than 30X30) in representation of the study area.
5. Since the river morphology of Geray is changing with time, frequent conduction of the channel during research work is essential.

5.2.2. Engineering Mitigation Recommendation

As it can be understand from the model results discussed all most large portion of the reach of the river is flooded with high inundation depth and decreasing as we go from the downstream to upstream of the river. The inundation depth is large in depth up to 5.99m and within this depth of flood the effect of flood on the agricultural land of the study area is about 84% as explained in Vulnerability.

For the portion of the flood plain a river training activities is recommended because of it’s the flood inundation. Measures to mitigate the impact of flooding in suburban areas can largely be divided into two groups - structural and non-structural:

- Structural measures: are those that involve physical works to lessen the effects of flooding, such as improvements to drainage infrastructure. These might otherwise be described as "engineered" solutions.
- Non-structural measures: are typically linked with town planning policies and building codes and involve longer-term consideration. These might include, for example, restrictions on where construction can take place, limitations on fill in floodplains and specification of minimum habitable floor levels for buildings.

This paper considers structural measures, or "engineering" works to mitigate the impacts of flooding.

A. Levees

A levee is a slope or embankment, typically but not always constructed parallel to the waterway that prevents or reduces flooding on the landward side. Levees have been used for thousands of years to provide flood protection. Levees can be a valuable flood protection measure and are often seen as an "obvious" solution to river flooding.

B. Dike

Dike means an embankment, wall, fill, piling, pump, gate, floodbox, pipe, sluice, culvert, canal, ditch, drain or any other thing that is constructed, assembled or installed to prevent the flooding of land;

The river training could be constructions to avoid the over bursting of the flood from the river banks and avoiding silting problems deposited within the river course also one mechanism to avoid flooding .Thus this part of the floodplain could be used for agricultural activities and development of any other infrastructures.

But for further recommendation and select the best methods, it is required risk analysis of the flooding in the flood plain .Thus this is out of this thesis work only.

REFERENCE

Abaje, I. (2009). Mapping Flood Vulnerable Areas in a Developing Urban Center of Nigeria.

Abramowitz, M., & Stegun, I. A. (1965). *Handbook of Mathematical Function.* Dvorer, New York.

Ackerman, c. T. (2009). *HEC-GeoRAS, GIS Tools for Support of HEC-RAS using ArcGIS* . Wahington DC.: US Army Corps of Engineers, Institute for water Resource (HEC).

Alemu, W. G. (2007). Flood Hazard and Risk Assessment in Fogera Woreda using GIS & Remote Sensing.

Aris, M. (2003). GIS modeling of River and Tidal Flood Hazards in a Waterfront City: Case study of Semarang city, Central Java, Indonesia.

Awlachew, S. (2000). Investigation of water Resources Aimed at Multi-Objective Development with Respect to Limited Data Situation: The Case of Abaya-Chamo Basin.

Benson, M. A. (1968). Uniform flood-frequency estimating methods for federal agencies. 891-908.

Bobee, B. (1975). *The log-Pearson Type III distribution and its application in hydrology*, 681-689.

Bobee, B., & Robitaille, R. (1977). The use of the Pearson Type 3 and log Pearson Type 3 distiributions revisited. 427-443.

Botes, & Smith. (2010). A New Spatial Planning Tool for the Delineation of Flood Risk Areas. *Planning Africa 2010 Conference.* South African Planning Institute.

Briaud, J.-L. H.-C. (2004). *Pier and contraction scour in cohesive soils.* Washington, D.C.: National Cooperative Highway Research Program Report 516, Transportation Research Board.

Brunner, P. (2013). Advance in hydrological engineering, unsteady flow hydrulics modle of lower Columbia River system.

Checko, T. (2014). Characteristics, classi fi cation and agricultural potential of soils of upper Yezat Micro Watershed, North Western Highlands of Ethiopia.

Chow, V. T. (1988). *Applied Hydrology* . Singapore: McGraw Hill Book Company.

Cutter, S. L. (1996). Societal Vulnerability to Environmental Hazards.

Dalrymple, T. (1960). *Manual of Hydrology: Part 3. Flood-Flow Techniques* . Washington D.C.: United States Government Printing Office.

David Ford, N. P. (2008). *Hydrologic Modeling System HEC-HMS.* Washington DC: US Army corps of Engineers, Hydrologic Engineering Center.

Djokic, D. (2012). Hydrologic and Hydraulic Modeling with ArcGIS. *Esri International User Conference.* San Diego, California.

DPPA. (2006). Joint Government and Humanitarian Partners: Flash appeal for the 2006 flood.

DPPC. (1978). *Flood Risk and Vulnerability in Different Regions of Ethiopia, Draft for Discussion.* Addis Ababa.

DPPC. (1996). *Flood Risk Areas in Ethiopia.* Addis Ababa.

Els, z. (2011). Data Availablity and Requirements for Flood Hazard Mapping in South Africa.

ERA. (2013). Drainage Design Manual. *Drainage Design Manual*. Addis Ababa, Ethiopia.

Ethiopian Road authorities, (. (2001). *Drainage design manual.* Addis Ababa, Ethiopia.

Fisher, R. A., & Tippett, L. H. (1928). *Limiting forms of the frequencyd istribudono f the largesto r.* Philadelphia: Cambridge.

Freeze, R. (1975). A stochastic-conceptaual analysis of one-dimensional ground water flow in nonuniform homogenoums media. 725-741.

Gary, B. W. (2016). *HEC-RAS River Analysis System Hydraulic Reference Manual.* Washington DC.: US Army Corps of Engineers, Hydrologic Engineerig Center.

Getahun YS, G. S. (2015). Flood Hazard Assessment and Mapping of Flood Inundation Area of the Awash River Basin in Ethiopia using GIS and HEC-GeoRAS/HEC-RAS.

Haile, A., & Reintijs, T. (2005). Effects of LIDAR DEM Resolution in Flood Modeling: A Model Sensitivity Study for the city of Tegucigalpa, Honduras.

Hargreaves, G., & Samani, Z. (1985). Reference Crop Evapotranspiration from Temperature Applied Engineering 1. 96-99.

Jayaseelan, A. (2006). Drought and Floods Assessment and Monitoring using Remote Sensing and GIS.

Krause, P., Boyle, D. P., & Base, F. (2005). Comparison of different efficiency criteria for hydrological model assessment.

Linsley, R. a. (1983). *PAULHUS, Hydrology for Engineers , McGraw-Hill Homoginity inconsistency.* Washigton D.C.

Liu, Q., Lee, J., & Jordan, M. (2016). A Kernelized Stein Discrepancy for Goodness-of-fit Tests. *The 33rd International Conference on Machine Learning*, (pp. 276–284). New York, New York, USA.

Monteith, J. L. (1965). Evaporation and Environment. - Symp.

Nash, J., & Sutcliffe, J. (1970). River flow forecasting through conceptual models part I — A discussion of principles. *Journal of Hydrology*, 282-290.

National Bridge Inspection Standards. (1992). Code of Federal Regulations. Washington, D.C: U.S. Government Printing Office.

Neitsch, S. e. (2005). *Soil & Water Assessment Tool Theoretical Documentation User's Manual.* Texas: Texas Water Resources Institute.

Parviz, K., & Mohammad, H. (2013). Efficiency of Hydraulic Models for Flood Zoning Using GIS (Case Study: Ay-Doghmush River Basin).

Rogger, M., Kohl, B., H. Pirkl, Viglione, A., Komma, J., Kirnbauer, R., et al. (2012). Runoff models and flood frequency statistics for design flood estimation in Austria. 456–457.

Sanyal, J., & Lu, X. (2005). Remote sensing and GIS-based flood vulnerability assessment of human settlement: A case study of Gygantic west bengal, India. Hydrol process.

Seleshi, Y., & Zanke, U. (2004). Recent changes in rainfall and rainy days in Ethiopia.

Shaw, E. (1988). *Hydrology in Practice.* Wokingham: Van Nostrand Reinhold International.

Stedinger, J., & Griffis, V. (2012). Flood frequency analysis in the United States: Time to update. 199–204.

Subramanya, K. (2009). *Flow in Open Channels.* New Delehi: Tata McGraw-Hill.

U.S. soil conservation service, U. (1938). SCS National Engineering Handbook. Washington.

Ujas Pandya, D. P. (2017). River Cross Section Delineation from the Google Earth for Development of 1D HEC-RAS Model - A Case of Sabarmati River, Gujarat, India .

Van Western and Hofstee, D. (2000). Seismic inversion for reservoir properties combining statistical rock physics and geostatistics.

Vedula, S., & Mujumdar, P. (2005). *Water Resources Systems: Modelling Techniques and Analysis.*

ANNEXES

Appendix A: Double Mass Curve of Stations near Finote Selam

Table 12: Mean annual precipitation of stations

year	Finote Selam	Debre Markos	Debre Worke	Felge Berhan	Mehal Meda
1990	2.84	3.47	1.69	5.1	2.29
1991	3.63	3.02	2.32	3.89	2.16
1992	1.06	3.41	1.98	4.89	2.34
1993	3.88	4.7	2.15	4.17	2.05
1994	3.26	3.31	2.1	4	2.38
1995	3.3	3.42	2.3	3.48	2.34
1996	3.4	4.24	2.56	3.59	2.78
1997	4.4	4.08	2.75	3.39	2.05
1998	4.19	3.42	3.36	4.04	2.91
1999	3.51	3.76	2	3.27	2.61
2000	4.27	3.94	3.68	3.77	2.45
2001	4.1	3.79	3.04	3.85	2.86
2002	3.08	3.64	1.7	3.05	2.1
2003	3.72	3.49	2.7	3.43	2.49
2004	3.58	3.62	2.43	3.42	2.37
2005	3.58	3.43	2.52	3.29	2.45
2006	3.69	4.2	2.58	3.99	2.83
2007	3.34	3.84	3.52	3.95	2.59
2008	3.8	3.61	2.63	3.21	2.15
2009	3.79	3.41	1.18	3.07	2.46
2010	3.75	3.69	2.82	4.08	2.11
2011	3.85	4.13	2.31	3.97	2.13
2012	3.34	3.45	2.33	3.26	2.36
2013	3.13	3.3	2.82	3.82	2.52
2014	3.24	3.68	2.06	3.08	1.63
2015	3.23	2.95	1.54	3.71	2.06

Table 13: Cumulative mean annual of the stations against Finote Selam

year	All stations average	cumulative of Finoteselam	Cumulative All stations
1990	3.14	2.84	3.14
1991	2.85	6.47	5.99
1992	3.16	7.53	9.15
1993	3.27	11.41	12.42
1994	2.95	14.67	15.37
1995	2.89	17.97	18.26
1996	3.29	21.37	21.55
1997	3.07	25.77	24.62

1998	3.43	29.96	28.05
1999	2.91	33.47	30.96
2000	3.46	37.74	34.42
2001	3.39	41.84	37.81
2002	2.62	44.92	40.43
2003	3.03	48.64	43.46
2004	2.96	52.22	46.42
2005	2.92	55.8	49.34
2006	3.4	59.49	52.74
2007	3.48	62.83	56.22
2008	2.9	66.63	59.12
2009	2.53	70.42	61.65
2010	3.18	74.17	64.83
2011	3.13	78.02	67.96
2012	2.85	81.36	70.81
2013	3.12	84.49	73.93
2014	2.61	87.73	76.54
2015	2.57	90.96	79.11

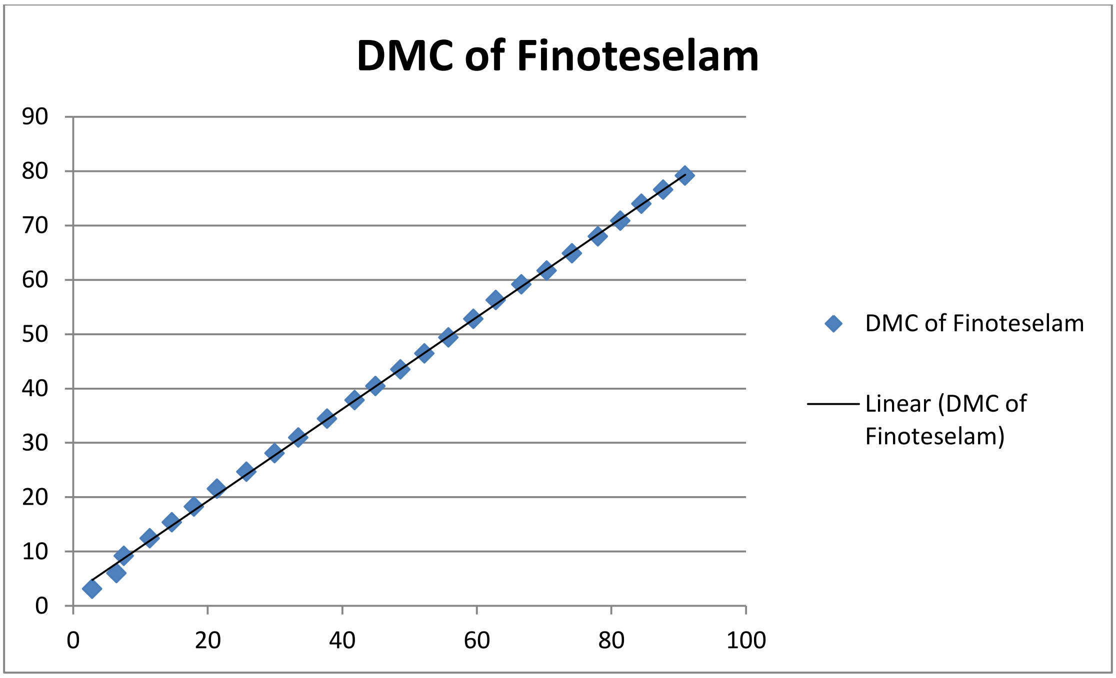


Figure A- 1: DMC of Finoteselam

Table 14: Cumulative mean annual of the stations against Debre Markos

year	Average All stations	Cumulative Debre Markos	cumulative All Station
1990	2.98	3.47	2.98
1991	3	6.49	5.98
1992	2.57	9.9	8.55

1993	3.06	14.6	11.61
1994	2.94	17.91	14.55
1995	2.86	21.33	17.41
1996	3.08	25.57	20.49
1997	3.15	29.65	23.64
1998	3.63	33.07	27.27
1999	2.85	36.83	30.12
2000	3.54	40.77	33.66
2001	3.46	44.56	37.12
2002	2.48	48.2	39.6
2003	3.09	51.69	42.69
2004	2.95	55.31	45.64
2005	2.96	58.74	48.6
2006	3.27	62.94	51.87
2007	3.35	66.78	55.22
2008	2.95	70.39	58.17
2009	2.62	73.8	60.79
2010	3.19	77.49	63.98
2011	3.07	81.62	67.05
2012	2.82	85.07	69.87
2013	3.07	88.37	72.94
2014	2.5	92.05	75.44
2015	2.63	95	78.07

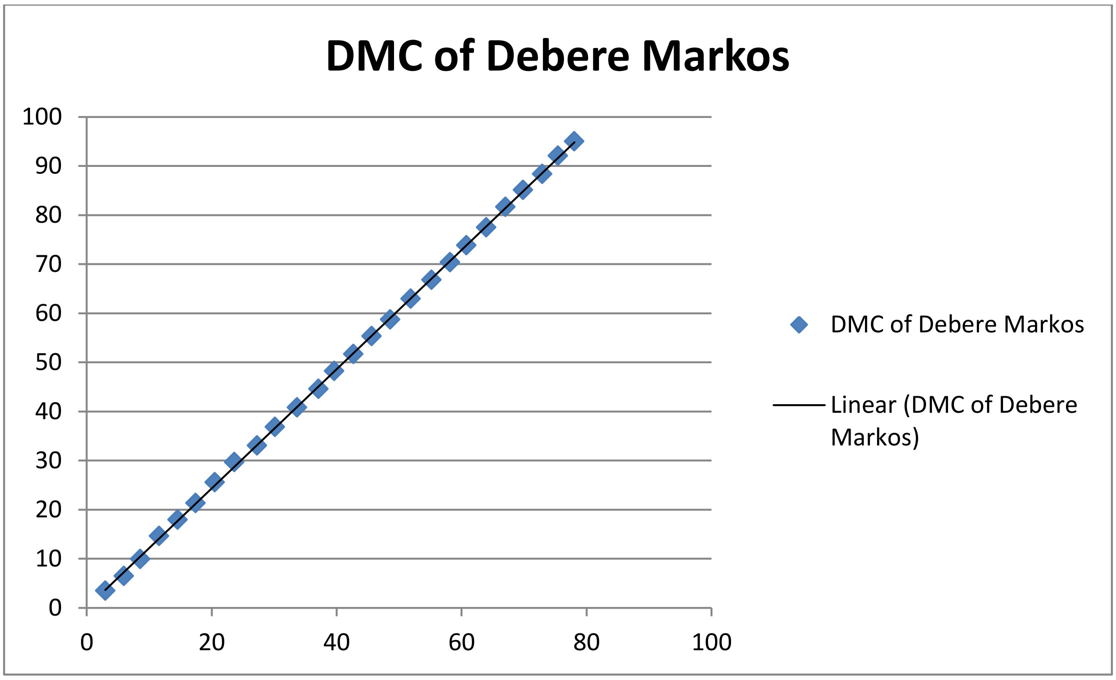


Figure A- 2: DMC of Debre Markos

Table 15: Cumulative mean annual of the stations against Debre Work

year	Average All Station	Cumulative Debre Worke	Cumulative All stations
1990	3.425	1.69	3.425
1991	3.175	4.01	6.6
1992	2.925	5.99	9.525
1993	3.7	8.14	13.225
1994	3.2375	10.24	16.4625
1995	3.135	12.54	19.5975
1996	3.5025	15.1	23.1
1997	3.48	17.85	26.58
1998	3.64	21.21	30.22
1999	3.2875	23.21	33.5075
2000	3.6075	26.89	37.115
2001	3.65	29.93	40.765
2002	2.9675	31.63	43.7325
2003	3.2825	34.33	47.015
2004	3.2475	36.76	50.2625
2005	3.1875	39.28	53.45
2006	3.6775	41.86	57.1275
2007	3.43	45.38	60.5575
2008	3.1925	48.01	63.75
2009	3.1825	49.19	66.9325
2010	3.4075	52.01	70.34
2011	3.52	54.32	73.86
2012	3.1025	56.65	76.9625
2013	3.1925	59.47	80.155
2014	2.9075	61.53	83.0625
2015	2.9875	63.07	86.05

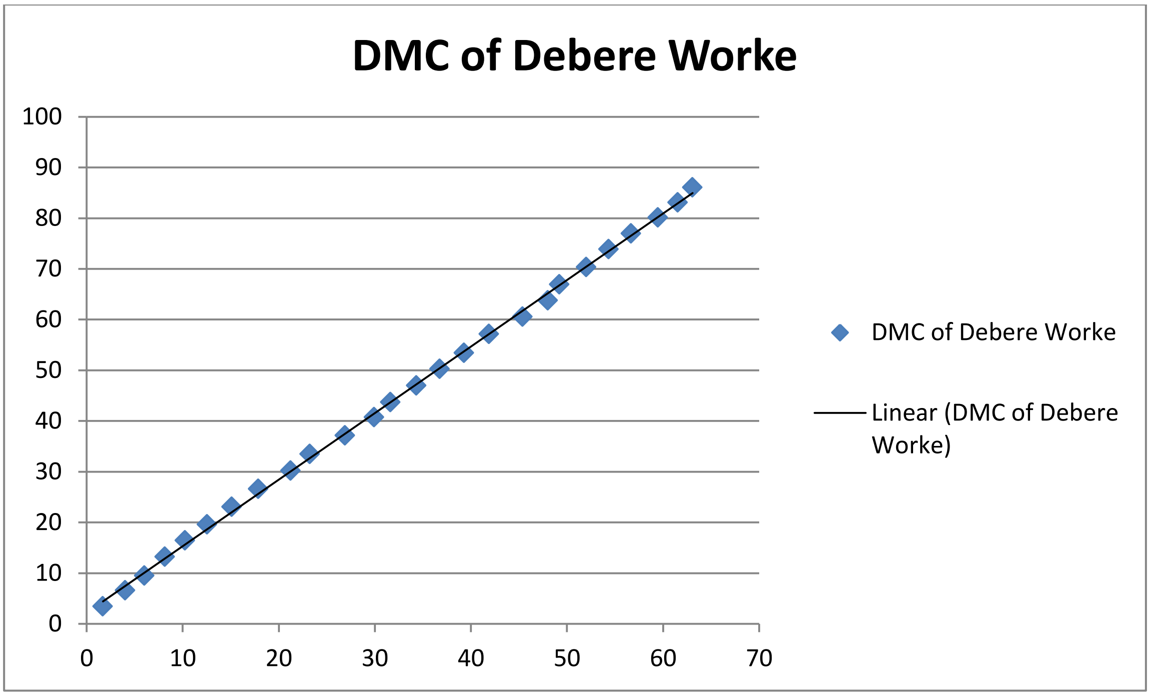


Figure A- 3: DMC of Debre Work

Table 16: Cumulative mean annual of the stations against Felege Birhan

year	Average All	Cumulative Felege Birhan	Cumulative All stations
1990	2.5725	5.1	2.5725
1991	2.7825	8.99	5.355
1992	2.1975	13.88	7.5525
1993	3.195	18.05	10.7475
1994	2.7625	22.05	13.51
1995	2.84	25.53	16.35
1996	3.245	29.12	19.595
1997	3.32	32.51	22.915
1998	3.47	36.55	26.385
1999	2.97	39.82	29.355
2000	3.585	43.59	32.94
2001	3.4475	47.44	36.3875
2002	2.63	50.49	39.0175
2003	3.1	53.92	42.1175
2004	3	57.34	45.1175
2005	2.995	60.63	48.1125
2006	3.325	64.62	51.4375
2007	3.3225	68.57	54.76
2008	3.0475	71.78	57.8075
2009	2.71	74.85	60.5175
2010	3.0925	78.93	63.61

2011	3.105	82.9	66.715
2012	2.87	86.16	69.585
2013	2.9425	89.98	72.5275
2014	2.6525	93.06	75.18
2015	2.445	96.77	77.625

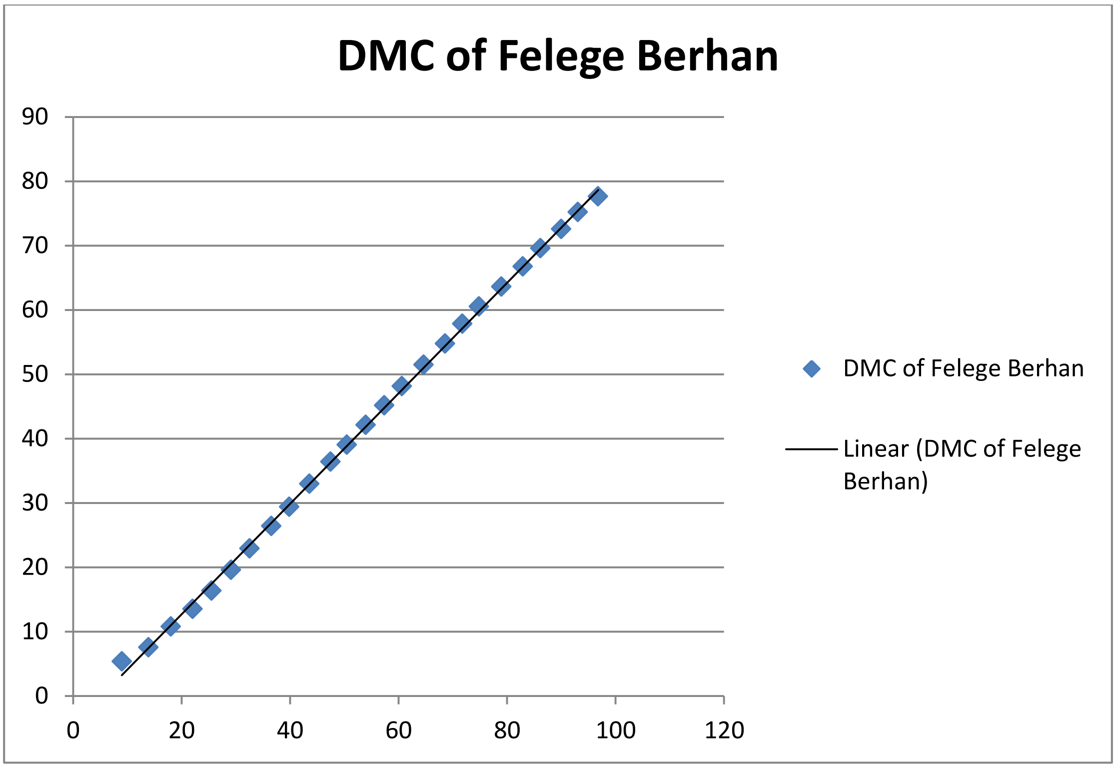


Figure A- 4: DMC of Felege Birhan

Table 17: Cumulative mean annual of the stations against Felege Birhan

year	Average All	Cumulative Mehal Meda	Cumulative All stations
1990	3.275	2.29	3.275
1991	3.215	4.45	6.49
1992	2.835	6.79	9.325
1993	3.725	8.84	13.05
1994	3.1675	11.22	16.2175
1995	3.125	13.56	19.3425
1996	3.4475	16.34	22.79
1997	3.655	18.39	26.445
1998	3.7525	21.3	30.1975
1999	3.135	23.91	33.3325
2000	3.915	26.36	37.2475
2001	3.695	29.22	40.9425
2002	2.8675	31.32	43.81
2003	3.335	33.81	47.145

2004	3.2625	36.18	50.4075
2005	3.205	38.63	53.6125
2006	3.615	41.46	57.2275
2007	3.6625	44.05	60.89
2008	3.3125	46.2	64.2025
2009	2.8625	48.66	67.065
2010	3.585	50.77	70.65
2011	3.565	52.9	74.215
2012	3.095	55.26	77.31
2013	3.2675	57.78	80.5775
2014	3.015	59.41	83.5925
2015	2.8575	61.47	86.45

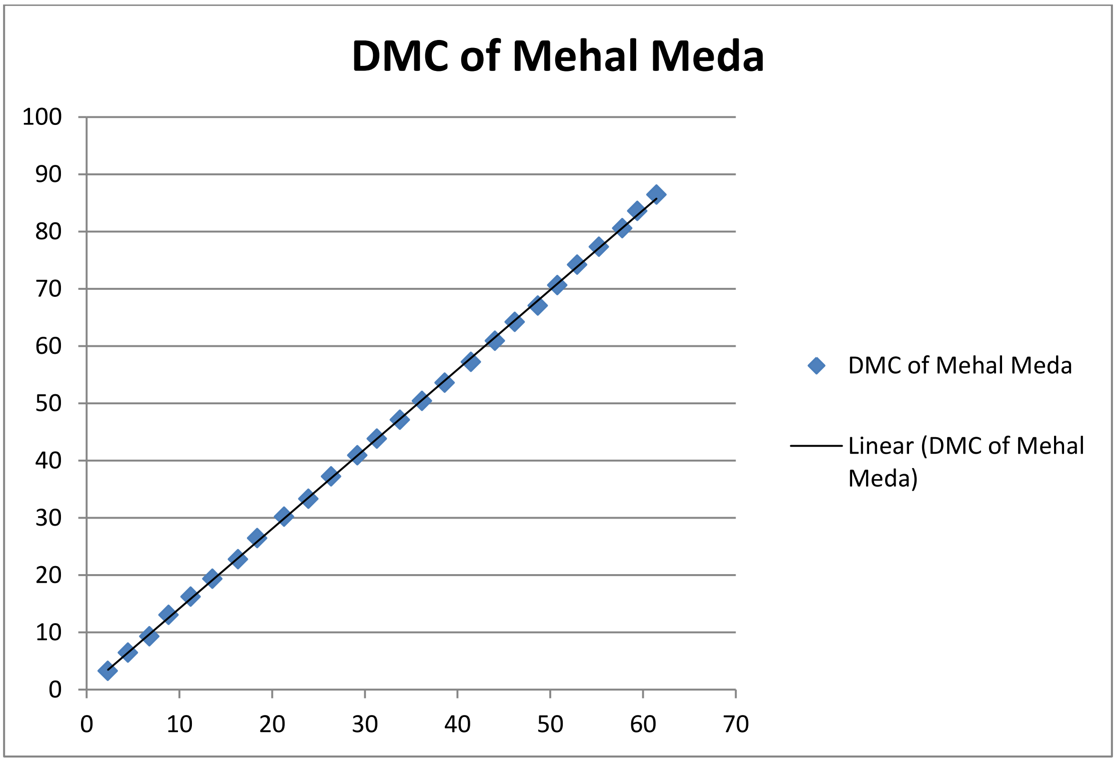


Figure A- 5: DMC of Mehal Meda

Appendix B: Homogeneity Test Analysis

Table 18: Finoteselam Station homogeneity data

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	$\overline{P}$
1990	16.8	28.7	20.2	52.1	50.3	99.9	291.9	281	164	31.5	2.1	0	1037.7
1991	0	8.656	63.7	14	58.79	145	521.7	261	131	90.5	13.7	17.9	1325
1992	16.72	53.72	0.468	35.8	41	0	0	0	0	112	72.9	53.5	385.84
1993	5.108	23.66	62.34	111	128.9	152	356	201	208	135	36	0	1417.6
1994	4.8	6.5	3.8	43.1	128.9	226	305.4	309	119	19.2	22.2	5	1192.1
1995	0	6.4	53.3	74.8	103.5	215	340.6	226	123	30.7	15.8	19.5	1208.1
1996	16	7.6	75.2	65.3	151.5	234	312.4	161	121	16.7	66.9	20.2	1247.7
1997	0	1	55.4	80.6	114.2	281	282.3	289	277	151	54.8	21.3	1608.4
1998	12.67	1.3	47.97	35.5	156.8	127	430.7	387	154	171	7.02	0	1530.5
1999	44.35	0	9.169	43.5	37.76	97.5	436.7	334	90.9	178	0.72	10.2	1282.9
2000	0	0	15.01	141	35.49	127	435.7	397	190	149	46.7	25.3	1563
2001	0	26.91	124.4	66.4	127.3	130	460.6	424	101	36.7	1.35	9.6	1508.1
2002	47.89	17.22	127	45	11.33	81.6	333.5	312	107	9.1	2.73	29	1123.7
2003	28.89	69.19	104.3	33.7	10.37	161	370.9	370	160	21.5	10.1	17.6	1357.2
2004	26.77	18.41	48.87	109	17.83	111	364	355	130	90.7	23.1	16.8	1311.8
2005	30.26	0.835	111.1	71.8	84.86	107	385.6	226	185	68.9	23.6	11	1306.4
2006	3.8	8	28	13	202.9	192	254.8	269	197	79	84.7	15.5	1347.7
2007	0	13.4	34.2	50.4	193.8	234	253.3	281	111	43.1	3.4	0	1217.9
2008	5.7	0	0	152	260.5	206	314.6	194	114	55.6	30.9	61.2	1393.2
2009	10	27.7	36.07	102	65.8	185	343.2	284	138	148	5.8	23	1368.6
2010	32.13	0	8.2	37.9	172.9	169	306.6	362	178	69.7	27.7	4.2	1368.3
2011	34.1	3.3	20.4	53.3	153.7	205	324.9	338	148	44.5	72	6.65	1403.6
2012	4.358	0.172	73.56	61.2	49.72	117	323.4	323	219	19.3	25.9	6.83	1222.7
2013	6.991	1.347	37.36	34.9	69.64	135	287.4	290	130	131	19.8	0.61	1143.5
2014	10.24	32.35	45.75	112	59.7	121	240.8	231	122	162	42.9	5.09	1184.8
2015	0	2.1	37.1	9.7	269.3	115	168.2	189	238	131	19.8	0.61	1179
$\overline{P}_i$	13.75	13.79	47.8	63.4	106	153	324.8	280	148	84.4	28.2	14.6	
Pi	**1.076**	**1.079**	**3.739**	**4.96**	**8.295**	**12**	**25.41**	**21.9**	**11.6**	**6.6**	**2.2**	**1.14**	

Table 19: Debre Worke station homogeneity data

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	$\overline{P}$
1990	6.7	36.5	56.7	48.6	49.47	27.7	171.8	127	81	5	1.4	4	615.87
1991	21.8	6.5	20.7	0.6	47.2	188.2	312.4	161.1	74.1	6.502	5.1	3.6	847.8
1992	10	26.2	34	49.2	54.2	27.9	144.2	187.7	34.7	77.1	40.1	40.4	725.71
1993	8.3	19.3	56.6	74.2	136.7	50.7	186.6	109.9	89.6	47.1	6.5	0	785.64
1994	0	24.9	14.1	23.3	48.91	48.2	276.2	247.9	80.2	3.055	0.6	0	767.36
1995	0.3	10.2	28.7	33	86.89	37.3	232.4	297.3	66.3	6	4.2	36.13	838.75

1996	42	0	63.9	137	87.43	154.9	191.6	168.9	74.8	0	15.1	0	936.05
1997	27.87	0	55.2	59.1	57.78	122.4	223.7	105.7	147	152.1	45.79	7.543	1004.6
1998	8.39	1.628	37.5	10.3	137.4	126.5	297.6	348	92	153.2	12	2	1226.5
1999	9.8	0	1	26.8	26.01	50.1	267	182.4	28	136.5	0	3.2	730.81
2000	0	0	14	114	36.4	71	378.6	400.5	127	107.1	62.5	36	1347.2
2001	0	24	84.8	25.1	92	107.3	294.2	379.7	76.3	19.5	0	7	1109.9
2002	15.2	6.8	85.7	4.3	0	41.9	231.3	197.2	34.5	0	0	5.4	622.3
2003	28	68	108	7.2	3.5	98.2	250.8	260.8	94.9	34.2	19.4	12.9	985.8
2004	14.8	6.3	23.4	63	9.6	46	249.9	292.8	71.6	92.7	5.4	12.4	887.9
2005	19.6	0	94.7	46.7	46.9	53.6	308.6	149.6	107	62.6	20	11	920.4
2006	1.5	0	49	38.1	72.74	91.96	240.6	245.9	124	36.12	21.2	22.59	943.45
2007	15.63	26.6	22.7	24.2	144.6	229.2	342.7	234.7	191	52.3	2.381	0	1285.9
2008	1.695	0	0	44.5	184.2	116.1	224.5	193	111	60.68	21.5	4	960.98
2009	7.9	14.06	38.4	29.7	52.3	83.65	39.3	39.08	52.3	60.28	1.2	14.2	432.38
2010	21.8	5	70.7	33.7	116.9	124.1	282	197.1	118	3	54.2	1.384	1027.9
2011	2	0	67	37.4	37	78.9	264.9	224.6	106	8.731	7.8	10	844.24
2012	0	0	69	37.4	45	78.9	270.9	220.1	106	8.5	7.8	10	853.5
2013	11	0	24.7	39.2	38.1	121	324	334.4	67.8	65.3	4.9	0	1030.4
2014	6.8	12.5	33.7	47.3	135.5	104.8	160.3	134.5	74.4	11.6	26.8	3	751.24
2015	0	8.091	38.6	3.3	86.71	78.7	110.4	60.1	24.2	130.7	19.82	0.613	561.18
$\overline{P}_i$	10.81	11.41	45.9	40.7	70.52	90.74	241.4	211.5	86.7	51.53	15.6	9.514	886.29
Pi	**1.22**	**1.287**	**5.18**	**4.59**	**7.957**	**10.24**	**27.24**	**23.87**	**9.78**	**5.814**	**1.761**	**1.073**	

Table 20: Felege Birhan station homogeneity data

Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	$\overline{P}$
1990	16.9	44.7	55.05	92.3	66.2	166	604.4	507.9	245.9	55.3	1.6	6.4	1862.5
1991	21.1	11.3	102.9	27.6	55	137	398.8	408.6	209	34.4	14.6	1.2	1421.3
1992	0	77.2	73.8	126	110.5	201	276.3	420.8	94.3	171.3	144	94.8	1789.8
1993	16	14.7	64.9	216	154.4	154	388.1	200.2	221.9	89.4	2	0	1521.8
1994	8.1	33	29.8	58.5	115	189	511.4	284.4	214.6	11.6	3.6	0	1458.5
1995	1	15.3	44.6	126	182.7	60.1	328.3	302.4	106.9	16.8	23.9	62.25	1270.4
1996	23.2	1.6	66.4	135	101.7	154	371.3	292.6	81.2	6.5	67.9	11.2	1312.7
1997	33	0.6	53.6	122	108.1	153	292.5	170.1	122.5	146.8	31.7	4.7	1238.2
1998	4.6	26.5	44	7.7	200.8	190	359.4	259.6	123.2	250.2	3.1	5	1473.8
1999	67.8	0	3	67.8	26.2	87.7	393.8	269.7	82.8	188	0.4	5.9	1193.1
2000	0	0	13.1	135	32.2	177	325.5	300.1	181.9	154.7	39.4	20.2	1378.7
2001	0	38.6	96.3	77.7	150.3	184	388.6	335.7	64.8	44.6	5.5	19.4	1405.8
2002	54.4	16.6	124	56.9	27	97.3	301.2	287.9	91.1	23.9	8.9	23.8	1113
2003	12	67.5	145	10	17.9	170	367.9	305.1	112.2	24.1	2.6	18.6	1252.9
2004	10.4	21.8	38.9	74.5	25.1	89	411.7	296.3	112.1	122.9	35.9	13.8	1252.4
2005	4.3	1.2	92.7	22.6	56.4	116	379.8	181.2	241.2	74.6	21	10.2	1200.8
2006	5.1	13.4	68.2	101	93.7	137	332.7	380.5	160.6	81.2	12.9	68.1	1454.6
2007	53.3	31.8	33.4	38.7	133.6	199	415.5	254.6	231.5	47.7	1.4	0	1440.5

2008	1.6	0	0.2	50.7	151.4	144	326.1	232	122.3	86.65	49.3	10.4	1174.5
2009	4.6	17.1	76.9	34.6	39.3	70.4	318.7	349.2	45.9	142.7	3.4	16.5	1119.3
2010	5.2	3.2	39.4	74.7	149.5	113	540.4	376.7	140.4	6.6	31.3	7.525	1488.1
2011	62.2	0.5	79.9	59.5	87.2	217	374.4	280.2	217.8	0.35	68.8	0	1448.3
2012	3.6	0.7	84.3	44.3	75.9	103	473.1	243.9	72	24.2	62.1	5.2	1192.1
2013	8.1	0.7	28.2	28	89	121	420.3	363.8	111.8	185.1	35.2	2.5	1394.1
2014	22	25.9	45.2	50.6	89.08	140	291.7	235.1	116.4	68.9	35.2	4.533	1124.7
2015	15.8	12.5	40.2	7.6	149.6	123	294	201.2	360.5	130.7	19.8	0.613	1355.1
$\overline{P}_i$	17.5	18.32	59.38	71	95.67	142	380.2	297.7	149.4	84.2	27.9	15.88	1359.1
Pi	**0.05**	**1.348**	**4.369**	**5.22**	**7.039**	**10.4**	**27.98**	**21.9**	**10.99**	**6.195**	**2.05**	**1.168**	

Table 21: Mehal Meda Station Homogeneity test data

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	$\overline{P}$
1990	4.972	83.88	39	45.84	0	72.53	230	209.5	128.6	15.4	4.24	0.38	834.4
1991	9.042	6.183	40.8	8.988	37.66	110.8	257.7	190.1	98.63	19.6	0	7.2	786.7
1992	43.5	31.92	14	96.72	17.38	16.94	240.1	264	58.87	43.3	10.3	19.8	856.8
1993	2.458	15.15	40.7	99.85	76.23	3.3	231.8	170.5	67.6	40.6	0	0	748.2
1994	0	0	78.6	32.7	9.3	27.6	313.5	312.3	83.7	3	8.7	0	869.4
1995	0	13.9	29	75.2	26.5	30.6	348.2	235.3	63.4	8.6	0	23.8	854.5
1996	53.4	0	127	6.614	75.6	91.9	294.6	306.4	37	2.3	21.3	0	1017
1997	41.5	0	9.6	38.2	14.2	100.7	269.4	163.4	30.7	55.9	23.4	1	748
1998	26.9	23	48.7	73.4	51.3	12.9	448.2	296.6	54.7	14.5	0	12	1062
1999	18.5	0	21.7	15.3	22.3	30.5	445.3	279	48.6	72	0	1.2	954.4
2000	0	0	11	96	18.5	32.9	337.6	289.5	77	10.8	13.4	9.3	896
2001	0	19.1	146	32.3	54.4	14.7	449.1	286.8	34.6	4.4	0	3.4	1045
2002	37.3	27.1	98.6	27.3	11.8	7.6	266.4	229.6	33.3	5.8	0	22.2	767
2003	23.9	32.3	43.6	60.9	6.6	73.8	322.4	247.5	84.1	0.1	5.4	8.9	909.5
2004	37.1	22.5	75.5	94.1	6	59.7	240.2	244.9	62.8	9.3	7.3	7.4	866.8
2005	54.4	1	63.9	97.1	108.6	54.5	243.2	198.3	67.4	3.7	1.4	0	893.5
2006	24.5	9	157	32.3	25.77	24.3	319.6	358.2	58.5	10.9	0	14	1034
2007	25.9	55.2	29.1	49.1	11.5	82.8	286.7	272.6	112.8	5.6	5.9	8	945.2
2008	1.9	5.1	0	33.4	27	40.8	302.8	187.5	95.46	32	61.8	0	787.8
2009	17.1	12.4	72.8	8.7	18.4	58.7	341.5	245.9	52.4	39.2	18.2	13.2	898.5
2010	12.2	50.2	38.9	105.8	64.5	30.7	325.5	64.5	47.4	6.8	3.2	21.7	771.4
2011	4.8	1.103	78.2	45.3	83.5	12.9	181.4	292.5	70.6	1.6	4.6	0	776.5
2012	0	0	54.3	71.7	38.6	78.2	362	229.1	18.9	12.4	0	0	865.2
2013	0	0	43.6	26.3	15.8	69.2	364.4	264.4	72.9	60.9	2	0	919.5
2014	0	49	31.4	21	29	10.1	169	146.9	96.72	19.6	20.4	1.4	594.5
2015	0	13.2	18.2	0	64.7	111.7	44.6	214.3	132.6	131	19.8	0.61	750.4
$\overline{P}_i$	16.9	18.12	54.3	49.77	35.2	48.48	293.7	238.4	68.82	24.2	8.9	6.75	863.5
Pi	**1.957**	**2.099**	**6.29**	**5.764**	**4.076**	**5.614**	**34.01**	**27.61**	**7.97**	**2.8**	**1.03**	**0.78**	

Table 22: Homogeneity test to fill missing data

Month	Finote selam	Debre work	Felege Birhan	Mehal Meda	Debre Markos
Jan	1.07594493	1.219808397	0.049447447	1.956935718	1.018867027
Feb	1.078575647	1.287036077	1.348174913	2.09888508	0.805954379
Mar	3.739475113	5.176140727	4.369258304	6.288709241	3.47332077
Apr	4.961255589	4.5911684	5.222338337	5.763916966	5.114516429
May	8.294873944	7.956770332	7.039360602	4.075959966	7.888291094
Jun	11.95114278	10.23804062	10.44778959	5.613777014	12.43321453
Jul	25.41035869	27.23744236	27.97561991	34.00661561	20.02032385
Aug	21.93914297	23.86743331	21.90199382	27.61224129	22.4791502
Sep	11.5988002	9.777748304	10.9937759	7.969568098	17.1171967
Oct	6.60069972	5.814448998	6.195021778	2.801130163	6.077996909
Nov	2.204738934	1.76050435	2.052779859	1.030422279	2.255453297
Dec	1.14499149	1.073458117	1.168253354	0.781838579	1.315714815

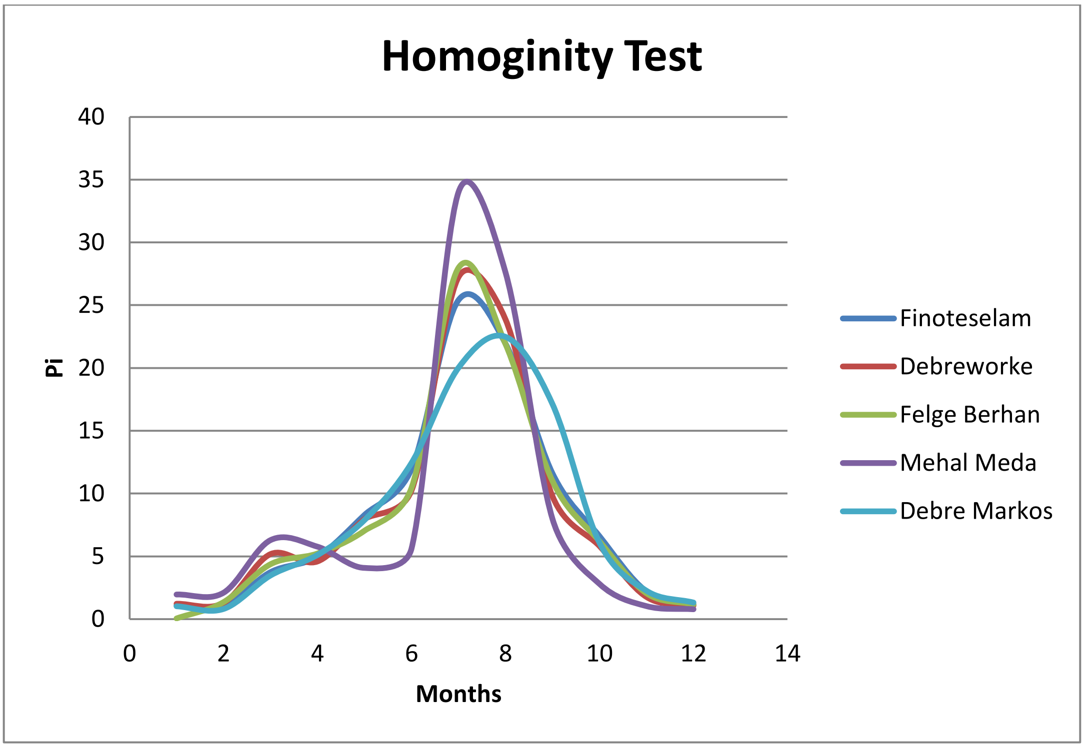


Figure A- 6: Homogeneity test graph

Appendix C: Estimated flow for Geray River

Table 23: Estimated monthly flow data for Geray River

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	16.34	6.943	2.646	0.832	18.913	4.056	1046	1943.1	532.73	257.93	39.872	13.64
1991	6.218	2.721	1.229	0.862	0.9984	79.71	1741	3893.9	1781.6	221.82	82.202	112.9
1992	87.52	13.67	6.759	8.542	15.986	146.4	1123	5355.6	902.71	632.51	406.07	123.3
1993	12.16	13.3	11.91	28.25	73.868	171.3	1707	1621.9	1066.6	512.58	177.21	68.1
1994	26.44	1.571	0.519	0.502	29.34	637.3	1920	2208.4	2425.5	161.66	49.553	50.13
1995	8.918	2.937	2.739	2.67	77.267	182.5	1431	1530.1	773.61	119.26	48.339	34.74
1996	20.67	8.148	26.54	44.84	251.37	522.8	2126	2869.2	967.03	291.36	80.756	30.37
1997	28.9	15.31	30.4	25	103.31	432	1451	1316.8	871.08	495.06	340.49	148
1998	51.21	17.28	10.25	5.024	50.973	208	1091	3083.3	1195.5	901.83	163.37	69.64
1999	54.61	19	8.816	8.103	54.55	270.8	1470	2639.1	1039.1	1331.7	153.55	58.06
2000	25.26	6.468	2.718	14.75	17.862	154.5	956.7	2544	1006.8	1005	247.65	81.5
2001	33.88	7.438	10.46	9.267	27.118	356.8	1128	2377.9	1183.4	316.3	247.65	81.5
2002	33.88	7.438	7.963	5.716	2.9626	182.4	1030	3557.6	943.96	151.67	77.183	128.3
2003	61.77	34.13	60.72	21.52	17.355	690.4	2021	2315.8	1176.5	342.42	108.22	73.44
2004	48.44	33.13	26.66	45.51	28.654	257.2	901.4	1328.5	889.71	824.95	138.78	82.43
2005	59.83	18.21	25.88	5.861	10.209	347.1	1020	1072.8	887.78	396.67	135.57	61.55
2006	39.08	24.45	14.03	6.056	10.209	347.1	1020	1072.8	887.78	396.67	135.57	61.55
2007	39.08	24.45	14.03	6.056	10.209	347.1	1020	1072.8	887.78	396.67	135.57	61.55
2008	39.08	24.9	14	46.07	28.438	276.1	936	1288.9	900.07	805.26	136.25	81.49
2009	59.18	36.35	32.19	5.946	10.075	377.5	1018	1079.4	879.99	374.52	132.39	60.69
2010	38.5	23.89	14	5.946	10.075	377.5	1018	1079.4	879.99	374.52	132.39	60.69
2011	38.5	23.89	14	5.946	10.075	377.5	1018	1079.4	879.99	374.52	132.39	60.69
2012	38.5	24.32	15.75	56.99	40.994	27.85	6.713	9.4214	452.12	1024.2	1046.9	898.5
2013	327.8	114.7	59.73	37.03	25.115	13.07	6.713	9.4214	452.12	1024.2	1046.9	898.5
2014	327.8	114.7	59.73	37.03	25.115	13.07	6.713	9.4214	452.12	1024.2	1046.9	898.5
2015	327.8	114.7	59.73	37.03	25.115	17.05	57.8	39.539	26.585	7.7549	8.4672	493.2

Appendix D: HEC-HMS outputs

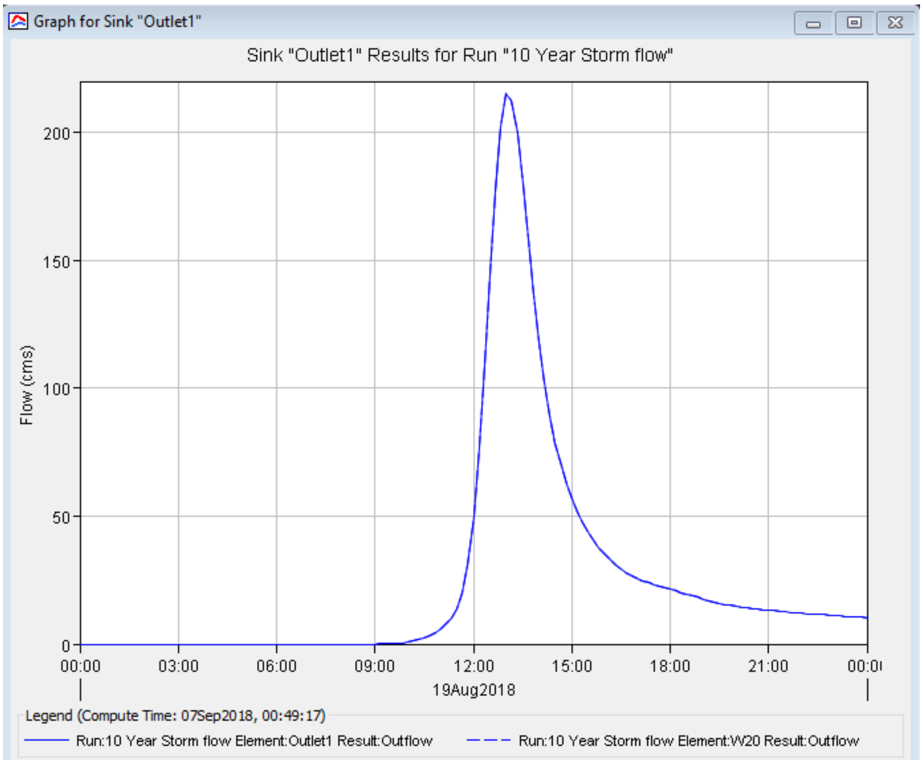


Figure A- 7: 10 year storm flow hydrograph

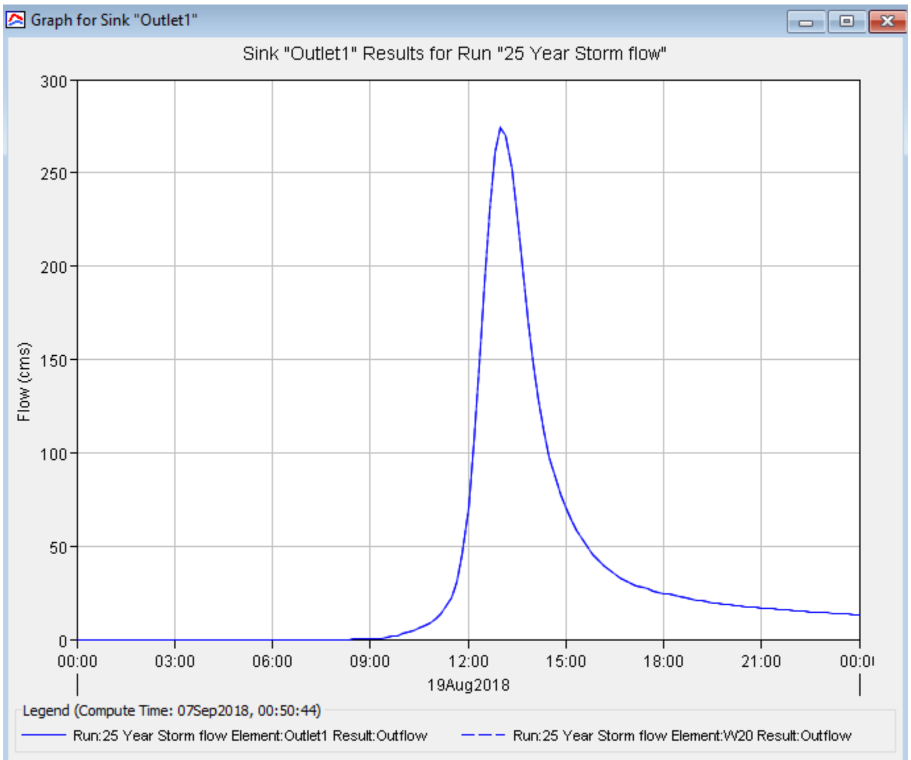


Figure A- 8: 25 year storm flow hydrograph

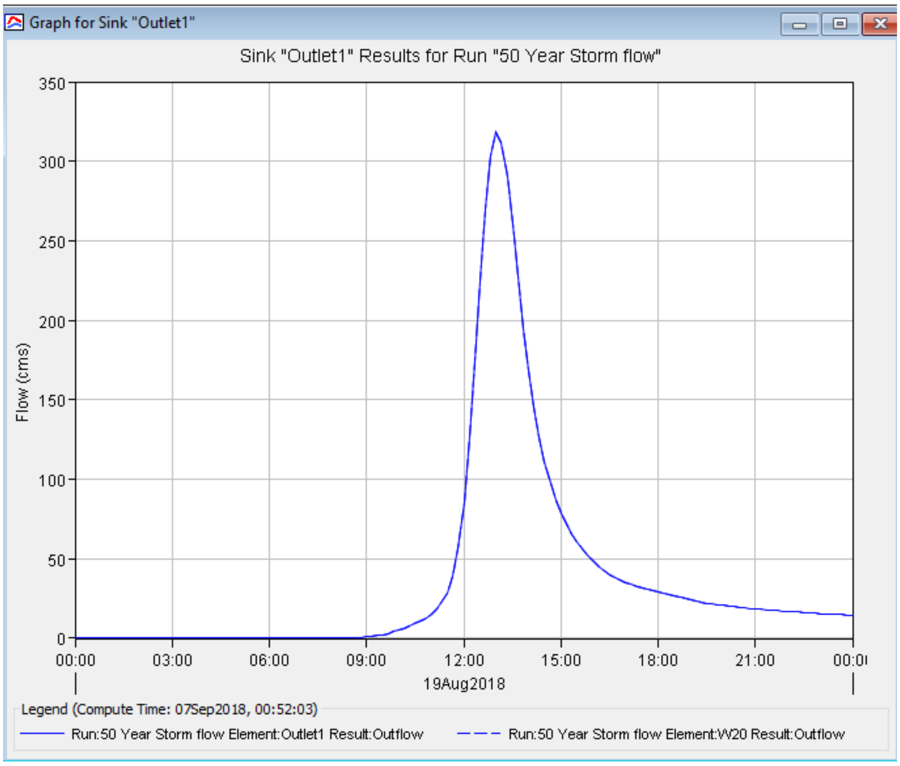


Figure A- 9: 50 year storm flow hydrograph

Appendix E: HEC-RAS outputs

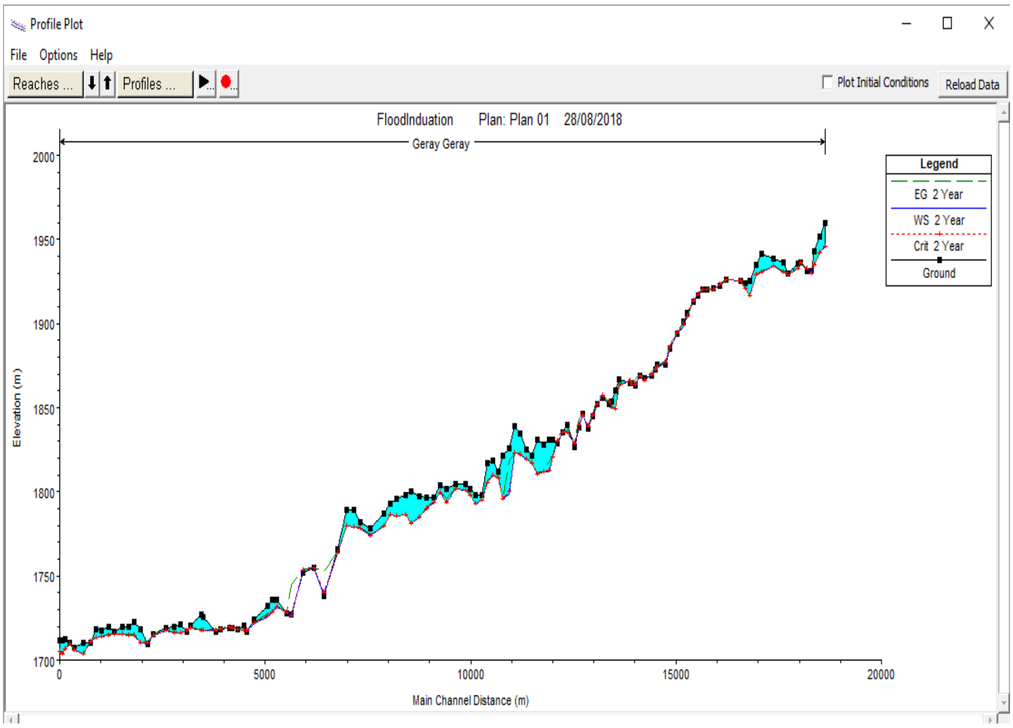


Figure A- 10: Water Surface Profile of 2 year storm

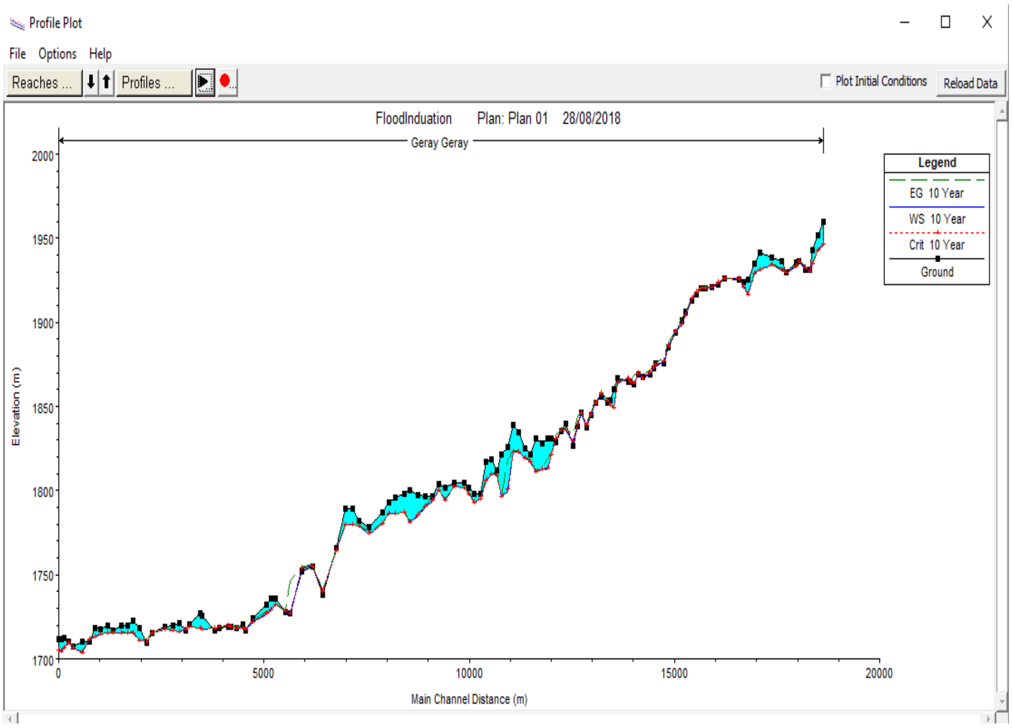


Figure A- 11: Water Surface Profile of 10 year storm

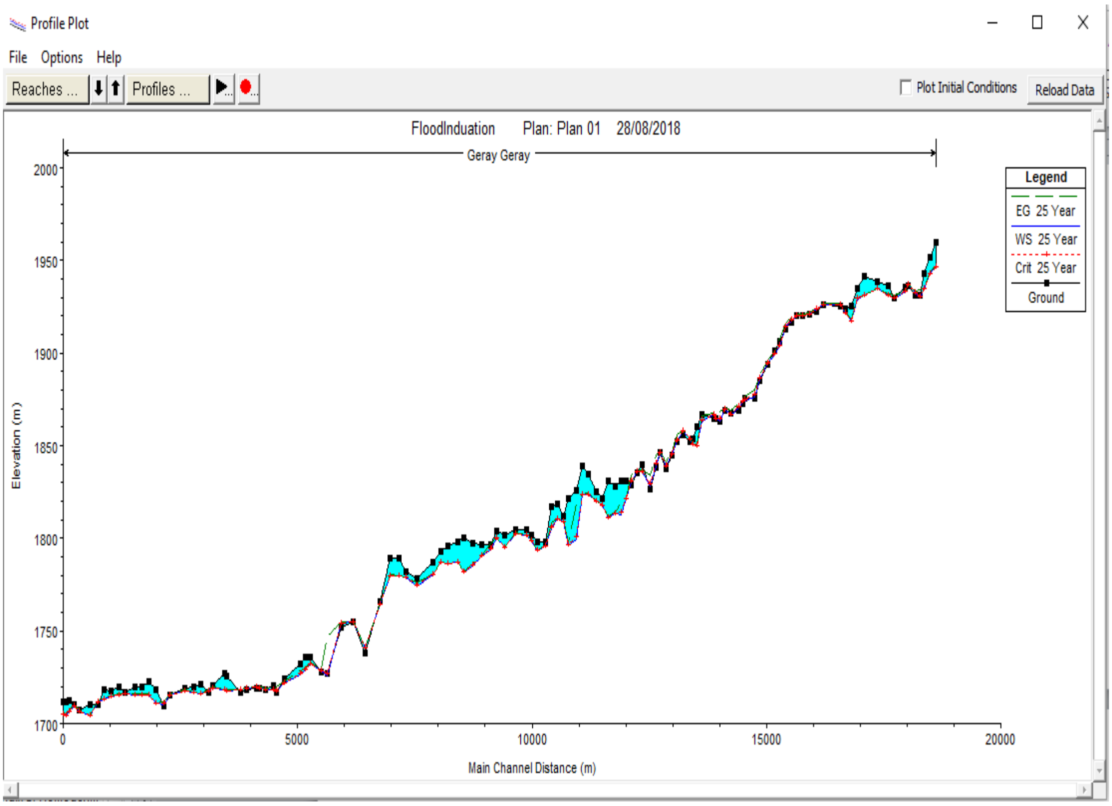


Figure A- 12: Water Surface Profile of 25 year storm

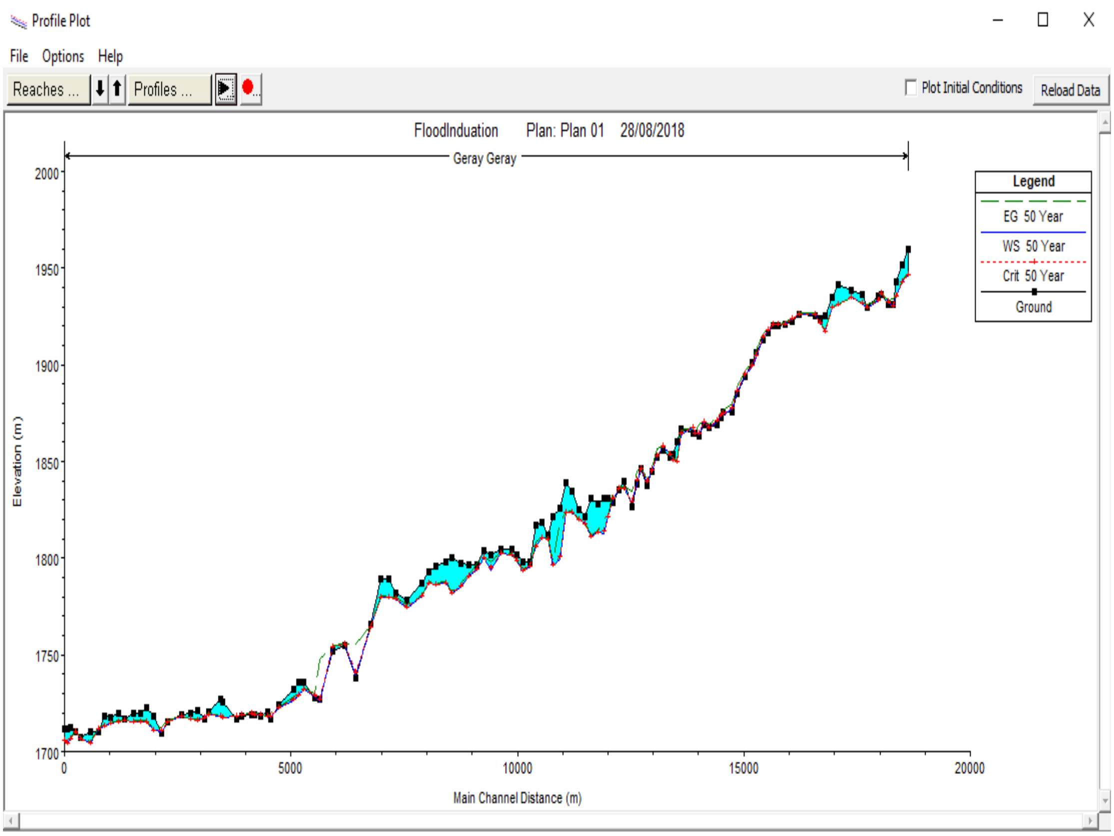


Figure A- 13: Water Surface Profile of 50 year storm

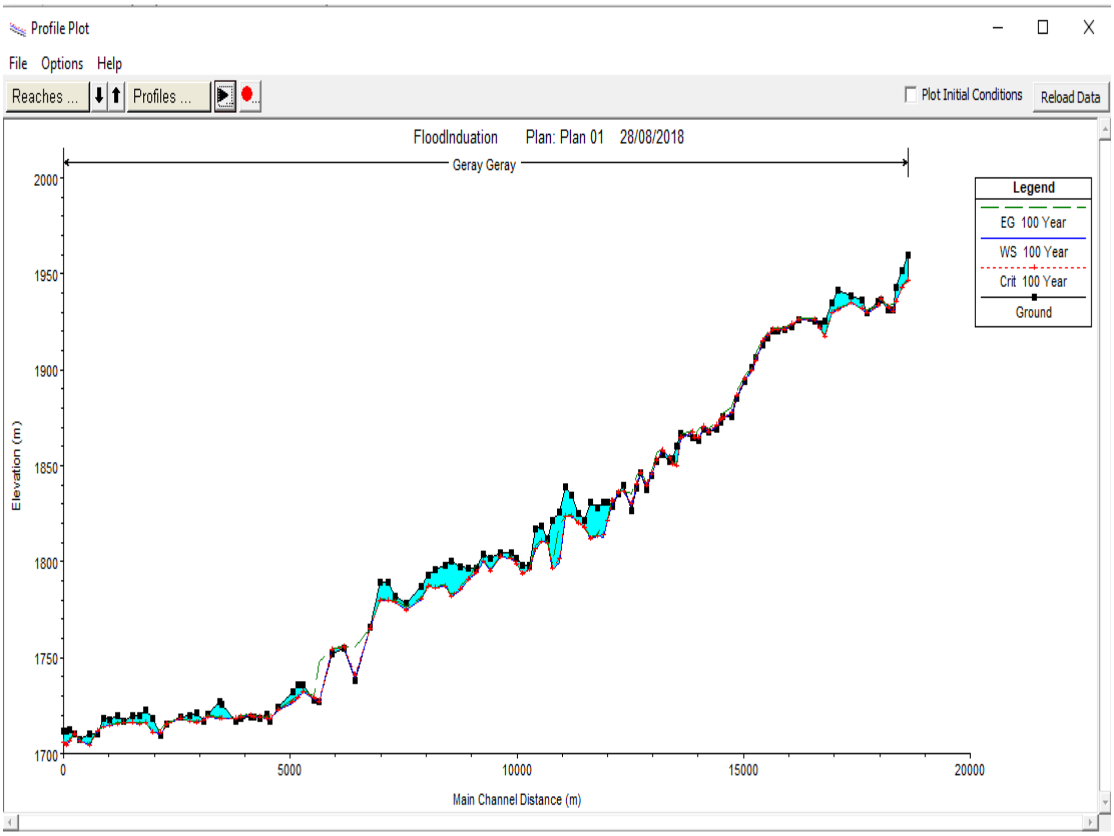


Figure A- 14: Water Surface Profile of 100 year storm

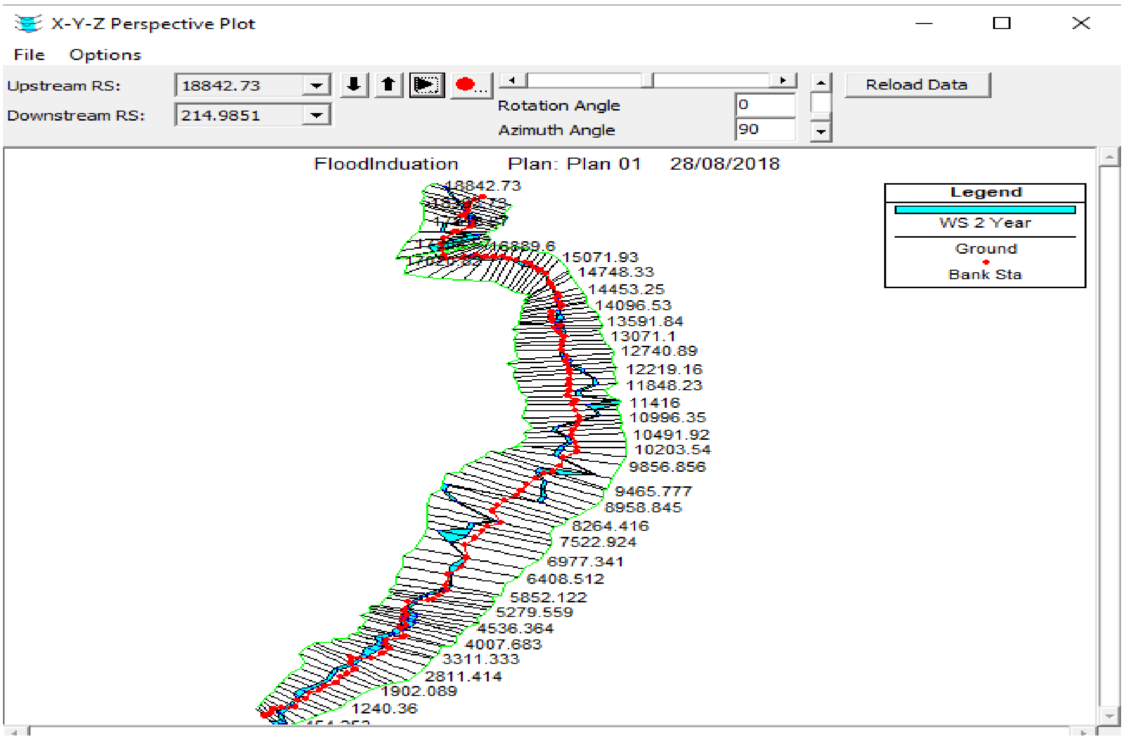


Figure A- 15: 3D view of 2 year flood

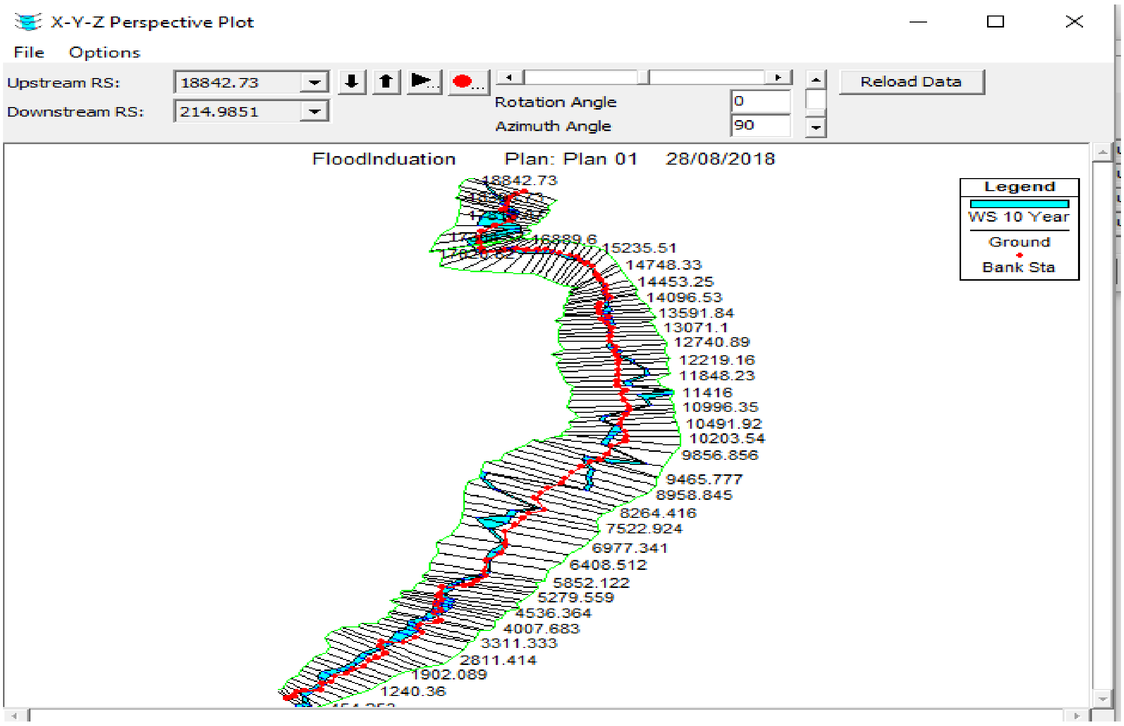


Figure A- 16: 3D view of 10 year flood

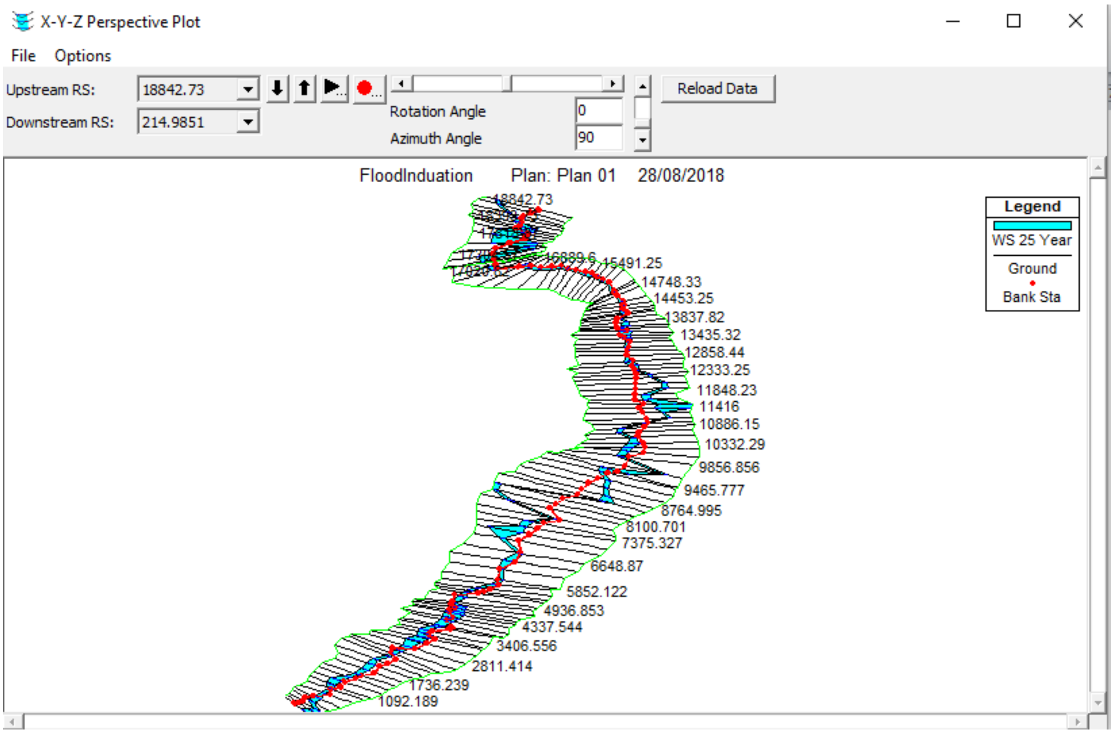


Figure A- 17: 3D view of 25 year flood

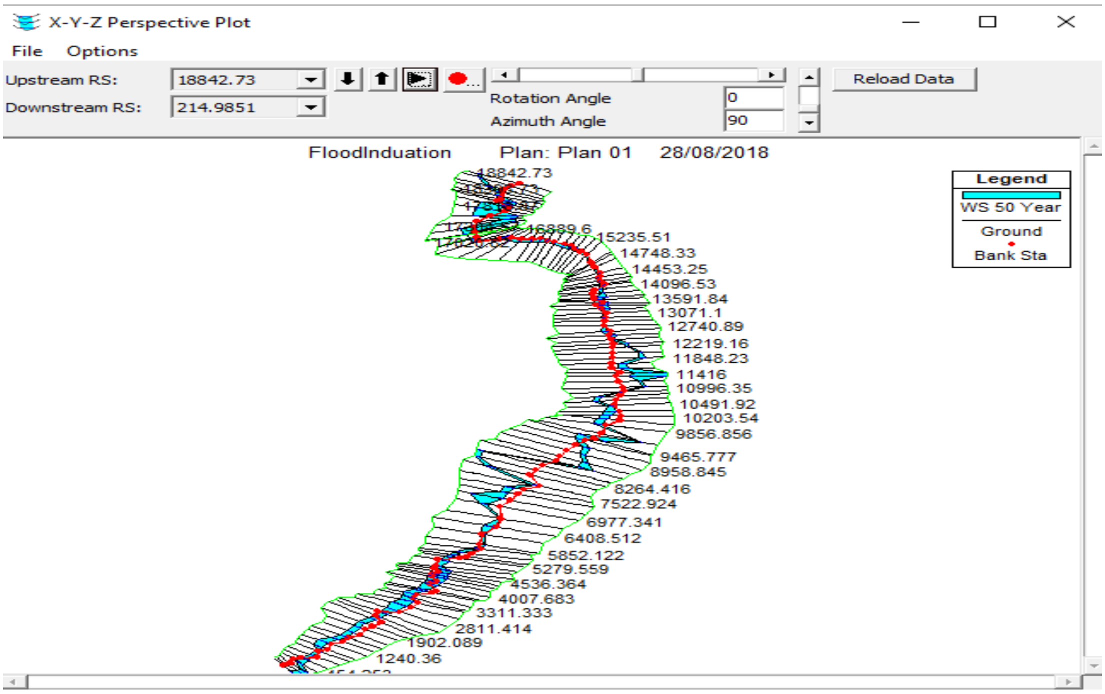


Figure A- 18: 3D view of 50 year flood

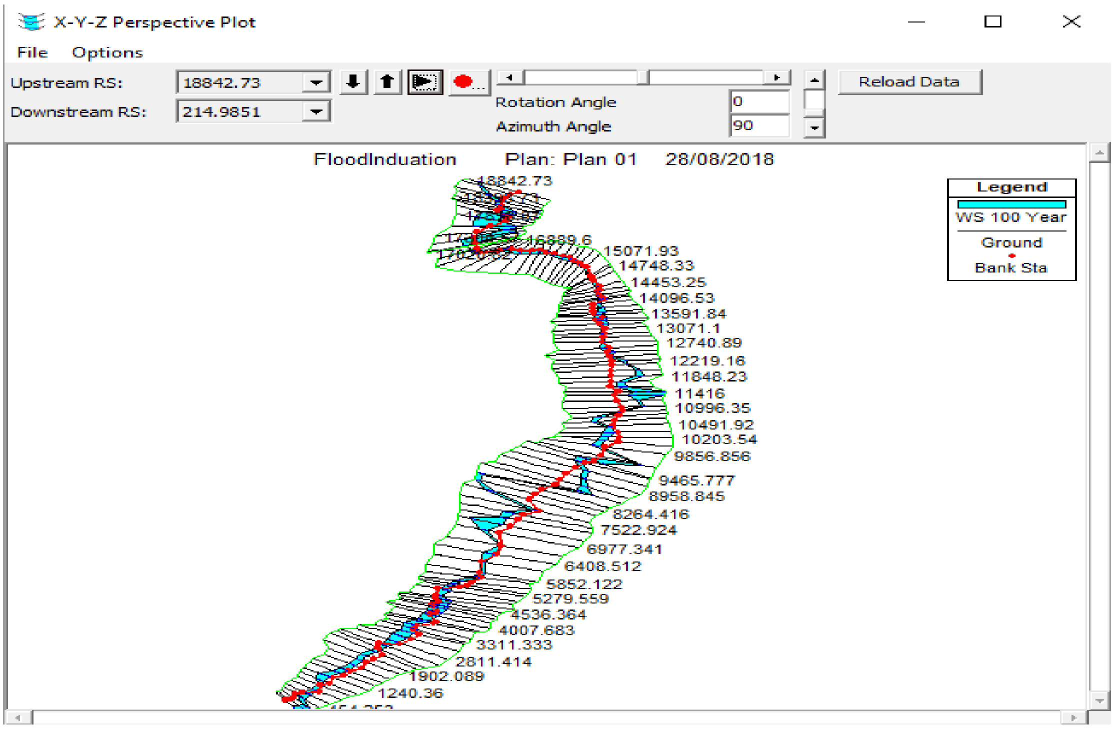


Figure A- 19: 3D view of 100 year flood

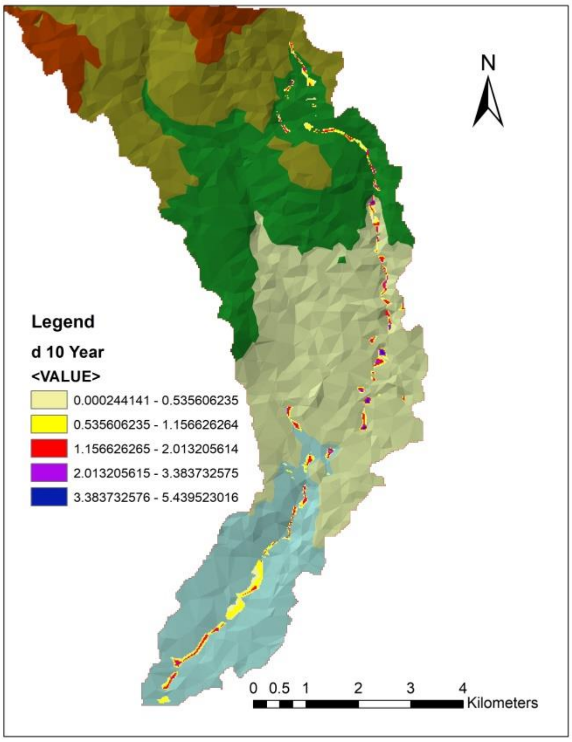


Figure A- 20: 10 year flood map and depth for the study area

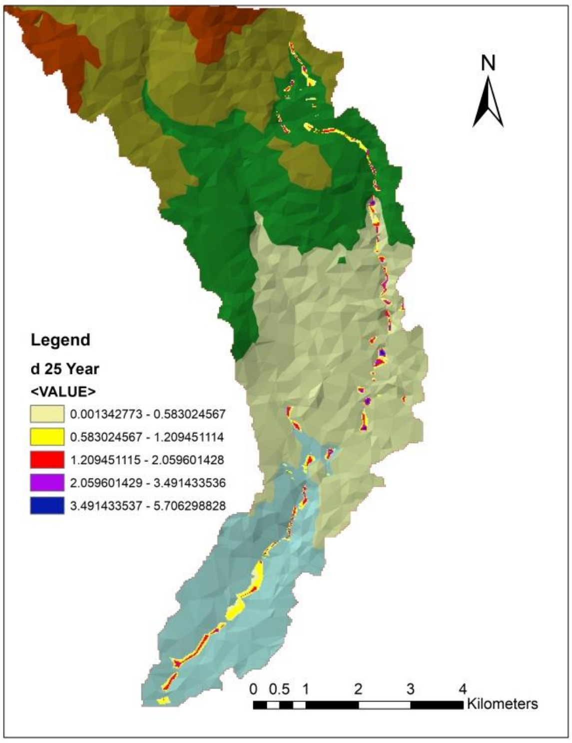


Figure A- 21: 25 year flood map and depth for the study area

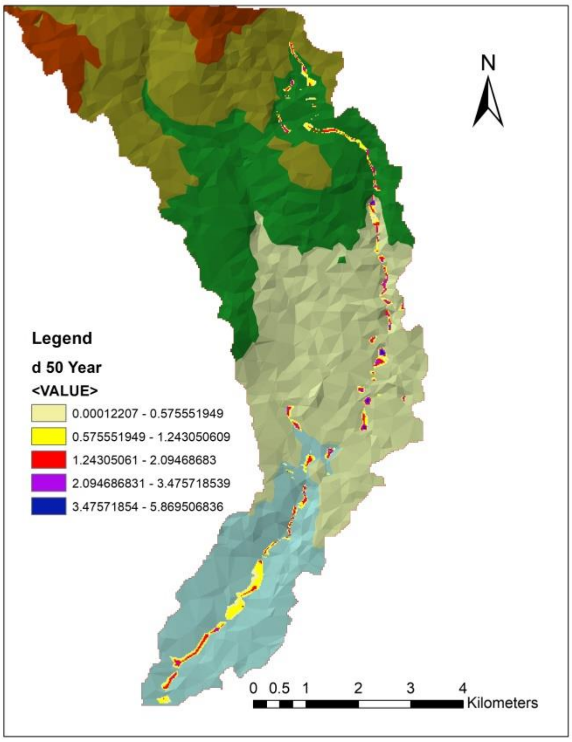


Figure A- 22: 50 year flood map and depth for the study area

Table 24: Profile Output table of HEC-RAS

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
Geray	18842.73	2 Year	109.10	1959.77	1945.76	1945.84	1946.24	0.013603		35.24	49.50	0.00
Geray	18842.73	10 Year	214.90	1959.77	1946.15	1946.31	1946.89	0.013601		56.58	58.46	0.00
Geray	18842.73	25 Year	274.40	1959.77	1946.33	1946.52	1947.18	0.013602		67.28	62.47	0.00
Geray	18842.73	50 Year	318.40	1959.77	1946.45	1946.67	1947.37	0.013604		74.80	65.14	0.00
Geray	18842.73	100 Year	362.70	1959.77	1946.56	1946.80	1947.55	0.013607		82.10	67.63	0.00
Geray	18710.04	2 Year	109.10	1951.50	1942.17	1942.17	1942.55	0.009781		40.29	54.04	0.00
Geray	18710.04	10 Year	214.90	1951.50	1942.63	1942.63	1943.13	0.009097		68.83	70.63	0.00
Geray	18710.04	25 Year	274.40	1951.50	1942.84	1942.84	1943.38	0.008664		84.21	78.12	0.00
Geray	18710.04	50 Year	318.40	1951.50	1942.97	1942.97	1943.54	0.008462		94.99	82.97	0.00
Geray	18710.04	100 Year	362.70	1951.50	1943.08	1943.08	1943.70	0.008476		104.67	87.09	0.00
Geray	18584.66	2 Year	109.10	1943.02	1934.51	1934.51	1934.89	0.009790		40.39	54.42	0.00
Geray	18584.66	10 Year	214.90	1943.02	1934.97	1934.97	1935.47	0.009009		69.29	71.28	0.00
Geray	18584.66	25 Year	274.40	1943.02	1935.18	1935.18	1935.72	0.008690		84.36	78.65	0.00
Geray	18584.66	50 Year	318.40	1943.02	1935.30	1935.30	1935.88	0.008571		94.80	83.38	0.00
Geray	18584.66	100 Year	362.70	1943.02	1935.43	1935.43	1936.03	0.008339		105.62	88.00	0.00
Geray	18503.42	2 Year	109.10	1931.40	1929.19	1929.84	1932.79	0.196615		12.98	30.19	0.00
Geray	18503.42	10 Year	214.90	1931.40	1929.50	1930.30	1933.55	0.145897		24.13	41.17	0.00
Geray	18503.42	25 Year	274.40	1931.40	1929.64	1930.51	1933.86	0.131236		30.16	46.03	0.00
Geray	18503.42	50 Year	318.40	1931.40	1929.73	1930.65	1934.06	0.122636		34.58	49.29	0.00
Geray	18503.42	100 Year	362.70	1931.40	1929.82	1930.77	1934.25	0.116112		38.92	52.30	0.00
Geray	18393.73	2 Year	109.10	1931.44	1932.40	1932.40	1932.65	0.009632	2.76	49.92	95.36	1.14
Geray	18393.73	10 Year	214.90	1931.44	1932.69	1932.69	1933.07	0.008993	3.11	78.91	102.25	1.15
Geray	18393.73	25 Year	274.40	1931.44	1932.83	1932.83	1933.28	0.008676	3.25	93.55	105.55	1.15
Geray	18393.73	50 Year	318.40	1931.44	1932.92	1932.92	1933.41	0.008671	3.42	102.96	107.63	1.16
Geray	18393.73	100 Year	362.70	1931.44	1933.01	1933.01	1933.54	0.008422	3.60	112.92	109.78	1.16
Geray	18246.1	2 Year	109.10	1936.58	1936.41	1936.41	1936.60	0.012459		55.99	147.70	0.00
Geray	18246.1	10 Year	214.90	1936.58	1936.65	1936.65	1936.90	0.011147	0.44	97.68	205.96	0.77
Geray	18246.1	25 Year	274.40	1936.58	1936.75	1936.75	1937.02	0.010274	0.79	121.27	238.76	0.86
Geray	18246.1	50 Year	318.40	1936.58	1936.83	1936.83	1937.10	0.009628	1.06	139.39	261.32	0.90
Geray	18246.1	100 Year	362.70	1936.58	1936.88	1936.88	1937.17	0.009283	1.30	154.36	272.98	0.94
Geray	18177.56	2 Year	109.10	1935.75	1932.82	1932.82	1933.02	0.012112		54.58	135.69	0.00
Geray	18177.56	10 Year	214.90	1935.75	1933.06	1933.06	1933.35	0.010818		89.73	156.28	0.00
Geray	18177.56	25 Year	274.40	1935.75	1933.17	1933.17	1933.50	0.010372		107.76	165.84	0.00
Geray	18177.56	50 Year	318.40	1935.75	1933.24	1933.24	1933.60	0.010125		120.49	172.28	0.00
Geray	18177.56	100 Year	362.70	1935.75	1933.31	1933.31	1933.69	0.009949		132.78	178.28	0.00
Geray	17932.65	2 Year	109.10	1929.89	1928.85	1929.26	1930.52	0.121181		19.09	55.21	0.00
Geray	17932.65	10 Year	214.90	1929.89	1929.08	1929.52	1931.12	0.098178		33.99	81.86	0.00
Geray	17932.65	25 Year	274.40	1929.89	1929.17	1929.62	1931.34	0.095594		42.05	103.34	0.00
Geray	17932.65	50 Year	318.40	1929.89	1929.22	1929.71	1931.47	0.095128		47.93	116.52	0.00
Geray	17932.65	100 Year	362.70	1929.89	1929.27	1929.78	1931.59	0.094839		53.79	128.35	0.00
Geray	17876.4	2 Year	109.10	1933.14	1925.17	1925.17	1925.70	0.008819		33.76	31.86	0.00
Geray	17876.4	10 Year	214.90	1933.14	1925.83	1925.83	1926.52	0.008146		58.69	43.30	0.00
Geray	17876.4	25 Year	274.40	1933.14	1926.11	1926.11	1926.86	0.007904		71.54	48.15	0.00
Geray	17876.4	50 Year	318.40	1933.14	1926.29	1926.29	1927.09	0.007837		80.38	51.22	0.00
Geray	17876.4	100 Year	362.70	1933.14	1926.47	1926.47	1927.30	0.007636		89.62	54.24	0.00

Geray	17818.87	2 Year	109.10	1936.44	1930.78	1930.78	1931.15	0.010000		40.30	54.97	0.00
Geray	17818.87	10 Year	214.90	1936.44	1931.28	1931.28	1931.71	0.007940		74.39	88.84	0.00
Geray	17818.87	25 Year	274.40	1936.44	1931.48	1931.48	1931.91	0.007526		93.87	108.72	0.00
Geray	17818.87	50 Year	318.40	1936.44	1931.60	1931.60	1932.04	0.007375		107.67	120.85	0.00
Geray	17818.87	100 Year	362.70	1936.44	1931.70	1931.70	1932.16	0.007408		120.22	130.90	0.00
Geray	17752.07	2 Year	109.10	1938.22	1928.63	1928.63	1928.98	0.010178		41.61	60.38	0.00
Geray	17752.07	10 Year	214.90	1938.22	1929.06	1929.06	1929.54	0.008982		70.16	73.37	0.00
Geray	17752.07	25 Year	274.40	1938.22	1929.25	1929.25	1929.78	0.008661		84.51	78.80	0.00
Geray	17752.07	50 Year	318.40	1938.22	1929.37	1929.37	1929.95	0.008458		94.73	82.38	0.00
Geray	17752.07	100 Year	362.70	1938.22	1929.49	1929.49	1930.10	0.008304		104.65	85.72	0.00
Geray	17630.43	2 Year	109.10	1938.44	1931.33	1931.33	1931.71	0.009866		39.96	53.30	0.00
Geray	17630.43	10 Year	214.90	1938.44	1931.79	1931.79	1932.29	0.008976		68.12	68.11	0.00
Geray	17630.43	25 Year	274.40	1938.44	1931.99	1931.99	1932.55	0.008571		82.36	73.30	0.00
Geray	17630.43	50 Year	318.40	1938.44	1932.12	1932.12	1932.73	0.008463		92.01	76.62	0.00
Geray	17630.43	100 Year	362.70	1938.44	1932.24	1932.24	1932.89	0.008299		101.74	79.82	0.00
Geray	17576.52	2 Year	109.10	1938.63	1933.83	1933.83	1934.17	0.010299		42.50	64.21	0.00
Geray	17576.52	10 Year	214.90	1938.63	1934.24	1934.24	1934.71	0.008750		71.71	83.70	0.00
Geray	17576.52	25 Year	274.40	1938.63	1934.57	1934.57	1934.90	0.005128		121.81	216.08	0.00
Geray	17576.52	50 Year	318.40	1938.63	1934.67	1934.67	1934.99	0.004923		144.56	238.80	0.00
Geray	17576.52	100 Year	362.70	1938.63	1934.75	1934.75	1935.08	0.004885		164.56	257.13	0.00
Geray	17438.18	2 Year	109.10	1938.22	1933.06	1933.06	1933.20	0.013614		64.16	221.94	0.00
Geray	17438.18	10 Year	214.90	1938.22	1933.22	1933.22	1933.45	0.011797		101.70	228.06	0.00
Geray	17438.18	25 Year	274.40	1938.22	1933.30	1933.30	1933.57	0.011092		120.60	231.08	0.00
Geray	17438.18	50 Year	318.40	1938.22	1933.36	1933.36	1933.65	0.010746		133.58	233.14	0.00
Geray	17438.18	100 Year	362.70	1938.22	1933.41	1933.41	1933.73	0.010519		145.85	235.06	0.00
Geray	17351.03	2 Year	109.10	1941.16	1929.78	1930.22	1931.26	0.062157		20.25	38.76	0.00
Geray	17351.03	10 Year	214.90	1941.16	1930.16	1930.68	1931.81	0.046987		37.82	54.14	0.00
Geray	17351.03	25 Year	274.40	1941.16	1930.33	1930.86	1932.02	0.044391		47.70	64.26	0.00
Geray	17351.03	50 Year	318.40	1941.16	1930.44	1930.98	1932.15	0.042423		54.95	70.77	0.00
Geray	17351.03	100 Year	362.70	1941.16	1930.54	1931.09	1932.27	0.040518		62.22	76.75	0.00
Geray	17304.57	2 Year	109.10	1941.26	1930.72	1930.72	1930.92	0.012328		55.06	140.55	0.00
Geray	17304.57	10 Year	214.90	1941.26	1930.96	1930.96	1931.25	0.010563		89.36	151.92	0.00
Geray	17304.57	25 Year	274.40	1941.26	1931.06	1931.06	1931.41	0.010255		105.80	157.08	0.00
Geray	17304.57	50 Year	318.40	1941.26	1931.14	1931.14	1931.51	0.009888		118.06	160.81	0.00
Geray	17304.57	100 Year	362.70	1941.26	1931.21	1931.21	1931.61	0.009728		129.35	164.18	0.00
Geray	17244.94	2 Year	109.10	1938.16	1930.32	1930.32	1930.64	0.009541		44.77	72.21	0.00
Geray	17244.94	10 Year	214.90	1938.16	1930.72	1930.72	1931.12	0.008852		77.89	97.38	0.00
Geray	17244.94	25 Year	274.40	1938.16	1930.88	1930.88	1931.32	0.008716		94.56	107.84	0.00
Geray	17244.94	50 Year	318.40	1938.16	1930.99	1930.99	1931.45	0.008512		106.94	115.00	0.00
Geray	17244.94	100 Year	362.70	1938.16	1931.09	1931.09	1931.58	0.008474		118.35	121.23	0.00
Geray	17157.17	2 Year	109.10	1935.07	1928.83	1928.83	1929.16	0.008078		45.34	68.80	0.00
Geray	17157.17	10 Year	214.90	1935.07	1929.23	1929.23	1929.65	0.007999		77.77	91.52	0.00
Geray	17157.17	25 Year	274.40	1935.07	1929.41	1929.41	1929.87	0.007907		94.45	101.24	0.00
Geray	17157.17	50 Year	318.40	1935.07	1929.51	1929.51	1930.00	0.008034		105.30	107.09	0.00
Geray	17157.17	100 Year	362.70	1935.07	1929.62	1929.62	1930.13	0.007848		117.47	113.30	0.00

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
Geray	17093.97	2 Year	109.10	1931.74	1925.23	1925.83	1927.63	0.089124		15.90	27.65	0.00
Geray	17093.97	10 Year	214.90	1931.74	1925.65	1926.36	1928.21	0.065190		30.33	39.78	0.00
Geray	17093.97	25 Year	274.40	1931.74	1925.84	1926.58	1928.47	0.058040		38.22	45.05	0.00
Geray	17093.97	50 Year	318.40	1931.74	1925.97	1926.73	1928.62	0.053570		44.14	48.63	0.00
Geray	17093.97	100 Year	362.70	1931.74	1926.08	1926.87	1928.78	0.050589		49.80	51.82	0.00
Geray	17020.82	2 Year	109.10	1925.67	1916.36	1916.36	1916.83	0.009245		35.73	38.24	0.00
Geray	17020.82	10 Year	214.90	1925.67	1916.94	1916.94	1917.56	0.008488		61.34	50.10	0.00
Geray	17020.82	25 Year	274.40	1925.67	1917.20	1917.20	1917.88	0.008103		74.98	55.39	0.00
Geray	17020.82	50 Year	318.40	1925.67	1917.36	1917.36	1918.09	0.007963		84.38	58.76	0.00
Geray	17020.82	100 Year	362.70	1925.67	1917.51	1917.51	1918.28	0.007859		93.49	61.86	0.00
Geray	16958.84	2 Year	109.10	1923.26	1917.39	1917.39	1917.83	0.009347		37.09	42.39	0.00
Geray	16958.84	10 Year	214.90	1923.26	1917.94	1917.94	1918.51	0.008483		63.96	55.66	0.00
Geray	16958.84	25 Year	274.40	1923.26	1918.17	1918.17	1918.81	0.008375		77.20	61.16	0.00
Geray	16958.84	50 Year	318.40	1923.26	1918.33	1918.33	1919.00	0.008089		87.44	65.08	0.00
Geray	16958.84	100 Year	362.70	1923.26	1918.47	1918.47	1919.18	0.007967		96.97	68.54	0.00
Geray	16889.6	2 Year	109.10	1924.01	1920.78	1920.78	1921.23	0.009471		36.96	42.44	0.00
Geray	16889.6	10 Year	214.90	1924.01	1921.33	1921.33	1921.91	0.008486		64.04	55.86	0.00
Geray	16889.6	25 Year	274.40	1924.01	1921.56	1921.56	1922.20	0.008382		77.29	61.37	0.00
Geray	16889.6	50 Year	318.40	1924.01	1921.72	1921.72	1922.40	0.008133		87.39	65.25	0.00
Geray	16889.6	100 Year	362.70	1924.01	1921.87	1921.87	1922.58	0.007928		97.29	68.85	0.00
Geray	16794.89	2 Year	109.10	1925.25	1925.62	1925.62	1925.92	0.009618	1.37	45.46	77.59	0.96
Geray	16794.89	10 Year	214.90	1925.25	1925.97	1925.97	1926.40	0.008193	2.34	74.92	89.90	1.04
Geray	16794.89	25 Year	274.40	1925.25	1926.13	1926.13	1926.62	0.007728	2.72	90.11	95.63	1.05
Geray	16794.89	50 Year	318.40	1925.25	1926.24	1926.24	1926.77	0.007494	2.96	100.79	99.46	1.06
Geray	16794.89	100 Year	362.70	1925.25	1926.35	1926.35	1926.91	0.007167	3.16	111.96	103.31	1.06
Geray	16745.62	2 Year	109.10	1929.94	1927.56	1927.56	1927.72	0.013513		61.93	202.78	0.00
Geray	16745.62	10 Year	214.90	1929.94	1927.75	1927.75	1927.96	0.012290		107.04	267.80	0.00
Geray	16745.62	25 Year	274.40	1929.94	1927.83	1927.83	1928.06	0.011913		130.18	295.66	0.00
Geray	16745.62	50 Year	318.40	1929.94	1927.89	1927.89	1928.13	0.011365		148.20	315.65	0.00
Geray	16745.62	100 Year	362.70	1929.94	1927.94	1927.94	1928.19	0.011173		164.50	332.72	0.00
Geray	16433.53	2 Year	109.10	1926.08	1925.67	1925.79	1926.09	0.021918		37.75	84.21	0.00
Geray	16433.53	10 Year	214.90	1926.08	1925.96	1926.10	1926.50	0.019096		66.10	111.43	0.00
Geray	16433.53	25 Year	274.40	1926.08	1926.09	1926.23	1926.67	0.017753	0.12	81.48	123.72	0.66
Geray	16433.53	50 Year	318.40	1926.08	1926.16	1926.33	1926.79	0.017115	0.63	91.16	130.83	0.98
Geray	16433.53	100 Year	362.70	1926.08	1926.24	1926.41	1926.89	0.016088	0.95	101.87	138.27	1.07
Geray	16275.58	2 Year	109.10	1922.48	1923.31	1923.37	1923.65	0.014705	2.69	42.30	90.21	1.34
Geray	16275.58	10 Year	214.90	1922.48	1923.54	1923.67	1924.09	0.016468	3.47	65.36	107.65	1.49
Geray	16275.58	25 Year	274.40	1922.48	1923.63	1923.81	1924.31	0.016905	3.90	75.64	112.06	1.54
Geray	16275.58	50 Year	318.40	1922.48	1923.69	1923.90	1924.46	0.017068	4.17	82.98	115.10	1.58
Geray	16275.58	100 Year	362.70	1922.48	1923.75	1923.99	1924.61	0.017481	4.44	89.62	117.79	1.62
Geray	16196.2	2 Year	109.10	1922.52	1921.44	1921.61	1922.02	0.023633		32.26	60.12	0.00
Geray	16196.2	10 Year	214.90	1922.52	1921.80	1922.01	1922.54	0.019260		56.27	74.96	0.00
Geray	16196.2	25 Year	274.40	1922.52	1921.95	1922.19	1922.78	0.018579		68.03	81.25	0.00
Geray	16196.2	50 Year	318.40	1922.52	1922.04	1922.31	1922.94	0.018361		76.11	85.30	0.00
Geray	16196.2	100 Year	362.70	1922.52	1922.14	1922.41	1923.09	0.018171		84.00	89.07	0.00
Geray	16130.15	2 Year	109.10	1920.94	1920.28	1920.29	1920.65	0.010474		40.73	58.48	0.00
Geray	16130.15	10 Year	214.90	1920.94	1920.65	1920.73	1921.21	0.011594		64.97	73.35	0.00
Geray	16130.15	25 Year	274.40	1920.94	1920.82	1920.92	1921.45	0.011769		77.54	79.98	0.00
Geray	16130.15	50 Year	318.40	1920.94	1920.92	1921.04	1921.62	0.011815		86.52	84.40	0.00
Geray	16130.15	100 Year	362.70	1920.94	1921.01	1921.14	1921.77	0.011858	0.48	94.14	88.00	0.80

Geray	16062.4	2 Year	109.10	1919.83	1920.13	1920.13	1920.48	0.009259	1.08	42.21	63.24	0.89
Geray	16062.4	10 Year	214.90	1919.83	1920.57	1920.57	1921.01	0.007467	1.87	74.63	83.42	0.95
Geray	16062.4	25 Year	274.40	1919.83	1920.74	1920.74	1921.23	0.007290	2.35	89.82	91.36	0.99
Geray	16062.4	50 Year	318.40	1919.83	1920.86	1920.86	1921.38	0.007180	2.64	100.68	96.64	1.02
Geray	16062.4	100 Year	362.70	1919.83	1920.96	1920.96	1921.53	0.007204	2.90	110.65	101.24	1.04
Geray	15982.82	2 Year	109.10	1919.88	1920.00	1920.00	1920.34	0.009940	0.61	42.42	64.81	0.80
Geray	15982.82	10 Year	214.90	1919.88	1920.42	1920.42	1920.87	0.008146	1.50	73.27	83.47	0.92
Geray	15982.82	25 Year	274.40	1919.88	1920.61	1920.61	1921.10	0.007558	1.77	89.92	91.98	0.94
Geray	15982.82	50 Year	318.40	1919.88	1920.73	1920.73	1921.25	0.007255	2.04	101.55	97.49	0.96
Geray	15982.82	100 Year	362.70	1919.88	1920.84	1920.84	1921.38	0.007064	2.32	112.57	102.44	0.98
Geray	15861.4	2 Year	109.10	1920.02	1919.89	1919.89	1920.24	0.010063		41.37	58.99	0.00
Geray	15861.4	10 Year	214.90	1920.02	1920.31	1920.31	1920.81	0.008715	1.04	69.03	70.96	0.86
Geray	15861.4	25 Year	274.40	1920.02	1920.51	1920.51	1921.07	0.008246	1.42	83.41	76.44	0.91
Geray	15861.4	50 Year	318.40	1920.02	1920.64	1920.64	1921.24	0.007970	1.63	93.74	80.15	0.94
Geray	15861.4	100 Year	362.70	1920.02	1920.76	1920.76	1921.40	0.007750	1.82	103.84	83.61	0.95
Geray	15755.13	2 Year	109.10	1916.45	1917.05	1917.41	1918.26	0.045704	5.32	22.58	45.16	2.42
Geray	15755.13	10 Year	214.90	1916.45	1917.36	1917.88	1919.08	0.036597	6.64	38.08	52.28	2.36
Geray	15755.13	25 Year	274.40	1916.45	1917.52	1918.10	1919.43	0.033240	7.11	46.48	55.77	2.31
Geray	15755.13	50 Year	318.40	1916.45	1917.63	1918.25	1919.66	0.031247	7.40	52.61	58.18	2.28
Geray	15755.13	100 Year	362.70	1916.45	1917.73	1918.39	1919.86	0.029532	7.65	58.74	60.49	2.25
Geray	15632.68	2 Year	109.10	1913.13	1913.64	1913.91	1914.51	0.027619	3.61	27.11	50.79	1.82
Geray	15632.68	10 Year	214.90	1913.13	1913.90	1914.34	1915.34	0.032902	5.53	41.46	57.50	2.16
Geray	15632.68	25 Year	274.40	1913.13	1914.01	1914.54	1915.75	0.035331	6.36	48.09	60.35	2.30
Geray	15632.68	50 Year	318.40	1913.13	1914.09	1914.68	1916.04	0.036797	6.90	52.68	62.25	2.39
Geray	15632.68	100 Year	362.70	1913.13	1914.16	1914.81	1916.32	0.037956	7.39	57.16	64.04	2.46
Geray	15491.25	2 Year	109.10	1906.38	1903.85	1903.85	1904.23	0.009794		40.44	54.60	0.00
Geray	15491.25	10 Year	214.90	1906.38	1904.30	1904.30	1904.83	0.008803		66.49	63.16	0.00
Geray	15491.25	25 Year	274.40	1906.38	1903.67	1904.50	1907.68	0.138317		30.95	51.12	0.00
Geray	15491.25	50 Year	318.40	1906.38	1903.75	1904.64	1907.96	0.128055		35.05	52.65	0.00
Geray	15491.25	100 Year	362.70	1906.38	1903.83	1904.78	1908.24	0.120682		38.99	54.08	0.00
Geray	15396.04	2 Year	109.10	1901.37	1898.20	1898.84	1901.77	0.193320		13.03	30.13	0.00
Geray	15396.04	10 Year	214.90	1901.37	1898.50	1899.32	1902.61	0.147922		23.96	40.86	0.00
Geray	15396.04	25 Year	274.40	1901.37	1898.92	1899.52	1900.90	0.047368		44.11	55.44	0.00
Geray	15396.04	50 Year	318.40	1901.37	1899.00	1899.66	1901.20	0.049460		48.52	58.14	0.00
Geray	15396.04	100 Year	362.70	1901.37	1899.07	1899.78	1901.48	0.051301		52.77	60.64	0.00
Geray	15235.51	2 Year	109.10	1893.57	1894.13	1894.39	1894.98	0.032068	4.50	28.18	64.98	2.04
Geray	15235.51	10 Year	214.90	1893.57	1894.34	1894.78	1895.78	0.037094	6.14	43.28	76.51	2.32
Geray	15235.51	25 Year	274.40	1893.57	1894.38	1894.94	1896.44	0.050077	7.39	46.31	78.63	2.72
Geray	15235.51	50 Year	318.40	1893.57	1894.45	1895.05	1896.69	0.049577	7.79	51.75	82.28	2.75
Geray	15235.51	100 Year	362.70	1893.57	1894.51	1895.16	1896.92	0.049262	8.16	57.01	85.66	2.78
Geray	15071.93	2 Year	109.10	1885.24	1885.47	1885.84	1887.41	0.204638	6.75	17.81	72.24	4.52
Geray	15071.93	10 Year	214.90	1885.24	1885.64	1886.19	1888.28	0.143888	8.17	30.09	74.46	4.15
Geray	15071.93	25 Year	274.40	1885.24	1885.75	1886.36	1888.40	0.106711	8.29	38.41	75.93	3.72
Geray	15071.93	50 Year	318.40	1885.24	1885.80	1886.47	1888.75	0.105265	8.78	42.31	76.61	3.76
Geray	15071.93	100 Year	362.70	1885.24	1885.85	1886.58	1889.07	0.103524	9.22	46.14	77.27	3.78
Geray	14958.16	2 Year	109.10	1875.87	1876.28	1876.74	1877.87	0.054011	3.21	19.84	36.25	2.27
Geray	14958.16	10 Year	214.90	1875.87	1876.54	1877.23	1879.20	0.061805	4.81	30.37	42.77	2.65
Geray	14958.16	25 Year	274.40	1875.87	1876.65	1877.44	1879.91	0.067328	5.53	35.04	45.35	2.83
Geray	14958.16	50 Year	318.40	1875.87	1876.73	1877.60	1880.28	0.067433	5.93	38.93	47.40	2.88
Geray	14958.16	100 Year	362.70	1875.87	1876.81	1877.74	1880.64	0.067628	6.29	42.68	49.30	2.93

Geray	14748.33	2 Year	109.10	1875.39	1873.88	1874.17	1874.84	0.032715		25.15	41.08	0.00
Geray	14748.33	10 Year	214.90	1875.39	1874.21	1874.67	1875.71	0.032489		39.56	45.85	0.00
Geray	14748.33	25 Year	274.40	1875.39	1874.36	1874.91	1876.13	0.032786		46.53	47.99	0.00
Geray	14748.33	50 Year	318.40	1875.39	1874.46	1875.06	1876.42	0.032997		51.38	49.42	0.00
Geray	14748.33	100 Year	362.70	1875.39	1874.55	1875.22	1876.68	0.033177		56.07	50.77	0.00
Geray	14706.19	2 Year	109.10	1872.96	1872.61	1873.03	1873.94	0.037762		21.33	30.24	0.00
Geray	14706.19	10 Year	214.90	1872.96	1873.03	1873.62	1874.86	0.035279	0.81	35.94	39.25	1.37
Geray	14706.19	25 Year	274.40	1872.96	1873.21	1873.87	1875.29	0.033404	1.81	43.16	43.02	1.64
Geray	14706.19	50 Year	318.40	1872.96	1873.32	1874.07	1875.59	0.032554	2.31	48.28	45.51	1.73
Geray	14706.19	100 Year	362.70	1872.96	1873.43	1874.23	1875.86	0.031964	2.72	53.27	47.80	1.79
Geray	14622.46	2 Year	109.10	1869.30	1869.54	1869.98	1870.88	0.026709	1.57	21.42	24.80	1.46
Geray	14622.46	10 Year	214.90	1869.30	1870.04	1870.66	1871.96	0.025459	3.26	35.61	31.97	1.72
Geray	14622.46	25 Year	274.40	1869.30	1870.24	1870.96	1872.45	0.025751	3.87	42.50	34.93	1.80
Geray	14622.46	50 Year	318.40	1869.30	1870.38	1871.16	1872.77	0.025879	4.24	47.38	36.88	1.84
Geray	14622.46	100 Year	362.70	1869.30	1870.51	1871.32	1873.06	0.025942	4.57	52.17	38.70	1.88
Geray	14453.25	2 Year	109.10	1867.87	1865.93	1866.33	1867.19	0.037235		22.01	32.41	0.00
Geray	14453.25	10 Year	214.90	1867.87	1866.29	1866.89	1868.23	0.040287		34.82	39.13	0.00
Geray	14453.25	25 Year	274.40	1867.87	1866.46	1867.14	1868.68	0.040417		41.53	42.23	0.00
Geray	14453.25	50 Year	318.40	1867.87	1866.57	1867.31	1868.98	0.040480		46.25	44.28	0.00
Geray	14453.25	100 Year	362.70	1867.87	1866.67	1867.46	1869.26	0.040489		50.87	46.20	0.00
Geray	14286.97	2 Year	109.10	1867.80	1869.08	1869.08	1869.51	0.007826	2.71	37.63	43.33	1.06
Geray	14286.97	10 Year	214.90	1867.80	1869.61	1869.61	1870.21	0.006865	3.74	64.24	57.83	1.09
Geray	14286.97	25 Year	274.40	1867.80	1869.85	1869.85	1870.52	0.006354	4.07	79.46	65.12	1.08
Geray	14286.97	50 Year	318.40	1867.80	1870.02	1870.02	1870.72	0.006068	4.28	90.54	69.95	1.08
Geray	14286.97	100 Year	362.70	1867.80	1870.17	1870.17	1870.90	0.005884	4.46	101.21	74.31	1.07
Geray	14225.99	2 Year	109.10	1863.17	1863.03	1863.70	1867.66	0.329499		11.44	32.48	0.00
Geray	14225.99	10 Year	214.90	1863.17	1863.30	1864.20	1868.55	0.200278	2.87	21.23	39.29	3.61
Geray	14225.99	25 Year	274.40	1863.17	1863.43	1864.41	1868.95	0.167716	4.18	26.57	42.55	3.71
Geray	14225.99	50 Year	318.40	1863.17	1863.52	1864.54	1869.20	0.151422	4.84	30.47	44.79	3.71
Geray	14225.99	100 Year	362.70	1863.17	1863.60	1864.68	1869.42	0.138746	5.36	34.37	46.92	3.68
Geray	14142.97	2 Year	109.10	1864.34	1863.94	1863.94	1864.32	0.009707		39.78	51.98	0.00
Geray	14142.97	10 Year	214.90	1864.34	1864.33	1864.42	1864.93	0.011343		62.39	65.10	0.00
Geray	14142.97	25 Year	274.40	1864.34	1864.47	1864.61	1865.21	0.012394	0.71	72.07	69.90	0.89
Geray	14142.97	50 Year	318.40	1864.34	1864.56	1864.74	1865.40	0.013031	1.04	78.50	72.29	1.00
Geray	14142.97	100 Year	362.70	1864.34	1864.65	1864.87	1865.58	0.013562	1.32	84.77	74.55	1.08
Geray	14096.53	2 Year	109.10	1864.82	1866.41	1866.41	1866.82	0.005192	3.48	44.65	56.12	0.96
Geray	14096.53	10 Year	214.90	1864.82	1866.92	1866.92	1867.45	0.004787	4.15	78.07	74.17	0.98
Geray	14096.53	25 Year	274.40	1864.82	1867.14	1867.14	1867.73	0.004684	4.43	95.23	81.90	0.98
Geray	14096.53	50 Year	318.40	1864.82	1867.29	1867.29	1867.90	0.004596	4.59	107.69	87.08	0.99
Geray	14096.53	100 Year	362.70	1864.82	1867.42	1867.42	1868.07	0.004617	4.77	118.94	91.51	1.00
Geray	13837.82	2 Year	109.10	1867.11	1863.25	1863.25	1863.78	0.009033		34.11	33.38	0.00
Geray	13837.82	10 Year	214.90	1867.11	1863.90	1863.90	1864.57	0.008152		58.94	43.88	0.00
Geray	13837.82	25 Year	274.40	1867.11	1863.34	1864.17	1866.16	0.046363		36.89	34.71	0.00
Geray	13837.82	50 Year	318.40	1867.11	1863.48	1864.36	1866.38	0.043571		42.22	37.14	0.00
Geray	13837.82	100 Year	362.70	1867.11	1863.63	1864.52	1866.58	0.040837		47.70	39.47	0.00
Geray	13739.31	2 Year	109.10	1860.47	1848.93	1848.93	1849.45	0.008862		34.27	33.29	0.00
Geray	13739.31	10 Year	214.90	1860.47	1849.57	1849.57	1850.26	0.008226		58.47	43.28	0.00
Geray	13739.31	25 Year	274.40	1860.47	1849.85	1849.85	1850.60	0.007909		71.23	47.71	0.00
Geray	13739.31	50 Year	318.40	1860.47	1850.03	1850.03	1850.83	0.007701		80.41	50.66	0.00
Geray	13739.31	100 Year	362.70	1860.47	1850.20	1850.20	1851.05	0.007571		89.21	53.34	0.00

Geray	13647.34	2 Year	109.10	1853.40	1850.23	1850.23	1850.45	0.012026		52.54	122.68	0.00
Geray	13647.34	10 Year	214.90	1853.40	1850.48	1850.48	1850.81	0.010230		83.96	126.81	0.00
Geray	13647.34	25 Year	274.40	1853.40	1850.60	1850.60	1850.99	0.009706		99.33	128.65	0.00
Geray	13647.34	50 Year	318.40	1853.40	1850.68	1850.68	1851.11	0.009604		109.36	129.83	0.00
Geray	13647.34	100 Year	362.70	1853.40	1850.76	1850.76	1851.23	0.009153		120.44	131.13	0.00
Geray	13591.84	2 Year	109.10	1852.43	1853.32	1853.32	1853.65	0.009034	2.81	43.19	67.86	1.12
Geray	13591.84	10 Year	214.90	1852.43	1853.73	1853.73	1854.18	0.007686	3.63	76.28	90.16	1.13
Geray	13591.84	25 Year	274.40	1852.43	1853.92	1853.92	1854.40	0.007194	3.91	94.02	99.70	1.12
Geray	13591.84	50 Year	318.40	1852.43	1854.04	1854.04	1854.55	0.007048	4.11	105.74	104.34	1.13
Geray	13591.84	100 Year	362.70	1852.43	1854.14	1854.14	1854.68	0.006958	4.29	116.94	108.59	1.13
Geray	13435.32	2 Year	109.10	1856.09	1857.45	1857.45	1857.72	0.004459	3.09	60.22	116.94	0.88
Geray	13435.32	10 Year	214.90	1856.09	1857.78	1857.78	1858.11	0.004500	3.64	104.21	141.17	0.92
Geray	13435.32	25 Year	274.40	1856.09	1857.91	1857.91	1858.28	0.004747	3.92	121.97	147.45	0.96
Geray	13435.32	50 Year	318.40	1856.09	1857.99	1857.99	1858.39	0.004854	4.10	134.62	151.76	0.98
Geray	13435.32	100 Year	362.70	1856.09	1858.07	1858.07	1858.50	0.005001	4.28	146.19	155.60	1.00
Geray	13306.82	2 Year	109.10	1852.38	1851.82	1852.23	1856.02	0.548503		12.01	61.54	0.00
Geray	13306.82	10 Year	214.90	1852.38	1851.96	1852.48	1856.44	0.440295		22.93	90.49	0.00
Geray	13306.82	25 Year	274.40	1852.38	1852.02	1852.59	1856.57	0.396199		29.07	103.27	0.00
Geray	13306.82	50 Year	318.40	1852.38	1852.07	1852.68	1856.66	0.371786		33.53	111.64	0.00
Geray	13306.82	100 Year	362.70	1852.38	1852.10	1852.76	1856.74	0.373632		38.05	118.89	0.00
Geray	13190.88	2 Year	109.10	1845.04	1845.18	1845.42	1845.96	0.053814	1.56	28.39	93.08	1.90
Geray	13190.88	10 Year	214.90	1845.04	1845.34	1845.66	1846.54	0.056960	3.58	46.20	128.04	2.38
Geray	13190.88	25 Year	274.40	1845.04	1845.41	1845.76	1846.76	0.056519	4.27	55.79	136.53	2.49
Geray	13190.88	50 Year	318.40	1845.04	1845.46	1845.84	1846.93	0.057122	4.71	61.91	138.55	2.56
Geray	13190.88	100 Year	362.70	1845.04	1845.50	1845.91	1847.06	0.056303	5.08	68.27	140.61	2.59
Geray	13071.1	2 Year	109.10	1837.83	1838.31	1838.70	1839.76	0.065292	5.74	20.49	45.25	2.82
Geray	13071.1	10 Year	214.90	1837.83	1838.59	1839.18	1840.71	0.052911	7.27	33.88	50.06	2.77
Geray	13071.1	25 Year	274.40	1837.83	1838.72	1839.40	1841.13	0.048958	7.86	40.82	52.38	2.74
Geray	13071.1	50 Year	318.40	1837.83	1838.82	1839.55	1841.40	0.046301	8.21	45.90	54.01	2.71
Geray	13071.1	100 Year	362.70	1837.83	1838.91	1839.69	1841.66	0.044438	8.55	50.78	55.54	2.70
Geray	12948.76	2 Year	109.10	1846.59	1845.43	1845.43	1845.91	0.009127		35.68	37.73	0.00
Geray	12948.76	10 Year	214.90	1846.59	1846.02	1846.02	1846.65	0.008274		61.55	49.56	0.00
Geray	12948.76	25 Year	274.40	1846.59	1846.28	1846.28	1846.96	0.008060		74.66	54.58	0.00
Geray	12948.76	50 Year	318.40	1846.59	1846.44	1846.44	1847.17	0.007938		83.95	57.88	0.00
Geray	12948.76	100 Year	362.70	1846.59	1846.59	1846.59	1847.37	0.007956		92.73	61.15	0.00
Geray	12858.44	2 Year	109.10	1838.18	1838.79	1839.56	1843.39	0.175226	10.93	12.18	28.03	4.81
Geray	12858.44	10 Year	214.90	1838.18	1839.13	1840.15	1844.41	0.110021	12.08	22.66	33.40	4.14
Geray	12858.44	25 Year	274.40	1838.18	1839.30	1840.42	1844.81	0.093071	12.49	28.47	36.04	3.92
Geray	12858.44	50 Year	318.40	1838.18	1839.42	1840.61	1845.07	0.084255	12.75	32.72	37.85	3.80
Geray	12858.44	100 Year	362.70	1838.18	1839.53	1840.77	1845.29	0.077017	12.96	37.04	39.61	3.68
Geray	12740.89	2 Year	109.10	1826.65	1827.71	1828.57	1831.51	0.064082	9.20	13.67	20.53	3.15
Geray	12740.89	10 Year	214.90	1826.65	1828.06	1829.32	1834.24	0.069588	12.03	21.60	24.57	3.48
Geray	12740.89	25 Year	274.40	1826.65	1828.23	1829.66	1835.36	0.069018	13.06	25.91	26.51	3.54
Geray	12740.89	50 Year	318.40	1826.65	1828.34	1829.87	1836.06	0.068133	13.68	29.06	27.84	3.56
Geray	12740.89	100 Year	362.70	1826.65	1828.45	1830.08	1836.68	0.067056	14.23	32.19	29.10	3.58
Geray	12563.41	2 Year	109.10	1839.41	1835.72	1835.72	1836.05	0.010176		42.74	64.54	0.00
Geray	12563.41	10 Year	214.90	1839.41	1836.12	1836.12	1836.59	0.009168		70.38	75.12	0.00
Geray	12563.41	25 Year	274.40	1839.41	1836.31	1836.31	1836.84	0.008701		84.96	80.14	0.00
Geray	12563.41	50 Year	318.40	1839.41	1836.43	1836.43	1837.00	0.008495		95.09	83.45	0.00
Geray	12563.41	100 Year	362.70	1839.41	1836.55	1836.55	1837.15	0.008325		104.97	86.55	0.00

Geray	12451.23	2 Year	109.10	1835.11	1835.68	1835.68	1835.94	0.010076	2.74	49.33	96.60	1.16
Geray	12451.23	10 Year	214.90	1835.11	1835.98	1835.98	1836.37	0.008748	3.39	79.53	103.84	1.17
Geray	12451.23	25 Year	274.40	1835.11	1836.12	1836.12	1836.57	0.008352	3.67	94.54	107.11	1.17
Geray	12451.23	50 Year	318.40	1835.11	1836.22	1836.22	1836.71	0.008092	3.85	105.22	109.38	1.17
Geray	12451.23	100 Year	362.70	1835.11	1836.31	1836.31	1836.84	0.007893	4.01	115.51	111.52	1.17
Geray	12333.25	2 Year	109.10	1828.99	1829.69	1830.34	1832.85	0.123383	6.98	13.93	27.79	3.76
Geray	12333.25	10 Year	214.90	1828.99	1830.05	1830.88	1833.69	0.093434	8.30	25.46	37.57	3.54
Geray	12333.25	25 Year	274.40	1828.99	1830.21	1831.13	1834.04	0.080372	9.12	31.93	42.09	3.42
Geray	12333.25	50 Year	318.40	1828.99	1830.32	1831.28	1834.26	0.073017	9.57	36.81	45.19	3.34
Geray	12333.25	100 Year	362.70	1828.99	1830.43	1831.43	1834.47	0.067121	9.93	41.74	48.12	3.27
Geray	12219.16	2 Year	109.10	1830.99	1820.86	1820.86	1821.21	0.009996		41.90	60.52	0.00
Geray	12219.16	10 Year	214.90	1830.99	1821.27	1821.27	1821.78	0.008828		67.58	65.84	0.00
Geray	12219.16	25 Year	274.40	1830.99	1821.46	1821.46	1822.05	0.008381		80.44	67.81	0.00
Geray	12219.16	50 Year	318.40	1830.99	1821.59	1821.59	1822.24	0.008190		89.25	69.12	0.00
Geray	12219.16	100 Year	362.70	1830.99	1821.71	1821.71	1822.41	0.007989		97.95	70.40	0.00
Geray	12126.39	2 Year	109.10	1830.66	1811.97	1812.94	1818.08	0.237188		9.97	17.86	0.00
Geray	12126.39	10 Year	214.90	1830.66	1812.41	1813.63	1819.04	0.153665		18.84	22.87	0.00
Geray	12126.39	25 Year	274.40	1830.66	1812.61	1813.94	1819.44	0.132673		23.70	25.20	0.00
Geray	12126.39	50 Year	318.40	1830.66	1812.75	1814.15	1819.69	0.121361		27.28	26.79	0.00
Geray	12126.39	100 Year	362.70	1830.66	1812.88	1814.33	1819.93	0.112487		30.84	28.28	0.00
Geray	11986.09	2 Year	109.10	1827.84	1812.24	1812.24	1812.79	0.008706		33.08	29.96	0.00
Geray	11986.09	10 Year	214.90	1827.84	1812.89	1812.93	1813.65	0.008591		55.83	39.72	0.00
Geray	11986.09	25 Year	274.40	1827.84	1813.15	1813.23	1814.02	0.008937		66.45	43.83	0.00
Geray	11986.09	50 Year	318.40	1827.84	1813.31	1813.42	1814.26	0.009140		73.88	46.50	0.00
Geray	11986.09	100 Year	362.70	1827.84	1813.46	1813.60	1814.48	0.009336		81.00	48.92	0.00
Geray	11848.23	2 Year	109.10	1831.33	1810.66	1810.66	1811.07	0.009657		38.46	47.59	0.00
Geray	11848.23	10 Year	214.90	1831.33	1811.15	1811.15	1811.73	0.008484		63.45	54.56	0.00
Geray	11848.23	25 Year	274.40	1831.33	1811.37	1811.37	1812.03	0.008207		75.91	57.72	0.00
Geray	11848.23	50 Year	318.40	1831.33	1811.52	1811.52	1812.24	0.008005		84.87	59.90	0.00
Geray	11848.23	100 Year	362.70	1831.33	1811.66	1811.66	1812.43	0.007842		93.60	61.94	0.00
Geray	11716.73	2 Year	109.10	1821.81	1816.88	1816.88	1817.25	0.009816		40.13	53.63	0.00
Geray	11716.73	10 Year	214.90	1821.81	1817.35	1817.35	1817.84	0.008917		69.17	70.41	0.00
Geray	11716.73	25 Year	274.40	1821.81	1817.54	1817.54	1818.09	0.008820		83.42	77.33	0.00
Geray	11716.73	50 Year	318.40	1821.81	1817.68	1817.68	1818.26	0.008479		94.65	82.37	0.00
Geray	11716.73	100 Year	362.70	1821.81	1817.80	1817.80	1818.41	0.008309		105.17	86.82	0.00
Geray	11576.09	2 Year	109.10	1825.36	1819.15	1819.15	1819.45	0.010838		45.52	79.25	0.00
Geray	11576.09	10 Year	214.90	1825.36	1819.52	1819.52	1819.90	0.009754		78.57	103.67	0.00
Geray	11576.09	25 Year	274.40	1825.36	1819.65	1819.65	1820.10	0.009423		93.02	106.79	0.00
Geray	11576.09	50 Year	318.40	1825.36	1819.75	1819.75	1820.23	0.009195		103.21	108.76	0.00
Geray	11576.09	100 Year	362.70	1825.36	1819.85	1819.85	1820.36	0.008772		114.04	110.82	0.00
Geray	11416	2 Year	109.10	1834.50	1822.52	1822.52	1823.04	0.009489		33.99	32.43	0.00
Geray	11416	10 Year	214.90	1834.50	1823.14	1823.14	1823.86	0.009203		57.17	42.05	0.00
Geray	11416	25 Year	274.40	1834.50	1823.63	1823.63	1824.14	0.005948		86.57	85.12	0.00
Geray	11416	50 Year	318.40	1834.50	1823.78	1823.78	1824.29	0.005902		101.21	101.60	0.00
Geray	11416	100 Year	362.70	1834.50	1823.91	1823.91	1824.42	0.005999		114.60	114.60	0.00
Geray	11294.01	2 Year	109.10	1838.89	1822.92	1822.92	1823.18	0.005815		48.51	91.78	0.00
Geray	11294.01	10 Year	214.90	1838.89	1823.24	1823.24	1823.49	0.006762		96.54	201.95	0.00
Geray	11294.01	25 Year	274.40	1838.89	1823.33	1823.33	1823.62	0.007447		115.34	207.39	0.00
Geray	11294.01	50 Year	318.40	1838.89	1823.39	1823.39	1823.70	0.007915		127.41	210.81	0.00
Geray	11294.01	100 Year	362.70	1838.89	1823.45	1823.45	1823.79	0.008039		140.67	214.50	0.00

Geray	11160.06	2 Year	109.10	1826.06	1799.11	1800.26	1818.75	1.276754		5.56	14.69	0.00
Geray	11160.06	10 Year	214.90	1826.06	1799.42	1800.86	1818.49	0.781240		11.11	20.77	0.00
Geray	11160.06	25 Year	274.40	1826.06	1799.56	1801.13	1818.74	0.669182		14.15	23.44	0.00
Geray	11160.06	50 Year	318.40	1826.06	1799.66	1801.31	1818.44	0.588941		16.59	25.38	0.00
Geray	11160.06	100 Year	362.70	1826.06	1799.74	1801.47	1818.97	0.557522		18.67	26.93	0.00
Geray	10996.35	2 Year	109.10	1821.56	1795.68	1795.68	1796.15	0.009065		35.80	37.86	0.00
Geray	10996.35	10 Year	214.90	1821.56	1796.26	1796.26	1796.90	0.008200		60.52	47.12	0.00
Geray	10996.35	25 Year	274.40	1821.56	1795.79	1796.51	1798.17	0.041648		40.15	39.64	0.00
Geray	10996.35	50 Year	318.40	1821.56	1795.90	1796.68	1798.48	0.041518		44.73	41.44	0.00
Geray	10996.35	100 Year	362.70	1821.56	1795.99	1796.85	1798.82	0.042606		48.67	42.93	0.00
Geray	10886.15	2 Year	109.10	1811.94	1808.50	1808.50	1808.96	0.009134		36.30	39.45	0.00
Geray	10886.15	10 Year	214.90	1811.94	1809.06	1809.06	1809.69	0.008395		61.25	49.51	0.00
Geray	10886.15	25 Year	274.40	1811.94	1809.31	1809.31	1810.01	0.008102		74.22	54.01	0.00
Geray	10886.15	50 Year	318.40	1811.94	1809.49	1809.49	1810.22	0.007829		83.84	57.11	0.00
Geray	10886.15	100 Year	362.70	1811.94	1809.64	1809.64	1810.42	0.007688		92.91	59.89	0.00
Geray	10759.38	2 Year	109.10	1818.37	1809.67	1809.67	1809.99	0.010364		43.53	68.51	0.00
Geray	10759.38	10 Year	214.90	1818.37	1810.07	1810.07	1810.49	0.009397		75.19	90.34	0.00
Geray	10759.38	25 Year	274.40	1818.37	1810.23	1810.23	1810.70	0.009288		90.85	99.60	0.00
Geray	10759.38	50 Year	318.40	1818.37	1810.35	1810.35	1810.84	0.009133		102.30	105.86	0.00
Geray	10759.38	100 Year	362.70	1818.37	1810.46	1810.46	1810.97	0.008816		114.39	112.10	0.00
Geray	10630.73	2 Year	109.10	1816.98	1805.28	1805.73	1807.01	0.092995		18.72	43.07	0.00
Geray	10630.73	10 Year	214.90	1816.98	1805.56	1806.14	1807.76	0.081331		32.72	56.95	0.00
Geray	10630.73	25 Year	274.40	1816.98	1805.69	1806.31	1808.03	0.075270		40.47	63.33	0.00
Geray	10630.73	50 Year	318.40	1816.98	1805.77	1806.43	1808.22	0.072313		45.93	67.47	0.00
Geray	10630.73	100 Year	362.70	1816.98	1805.85	1806.53	1808.42	0.070688		51.07	71.15	0.00
Geray	10491.92	2 Year	109.10	1797.71	1794.90	1794.90	1795.24	0.010228		42.21	62.83	0.00
Geray	10491.92	10 Year	214.90	1797.71	1795.31	1795.31	1795.79	0.009171		70.31	74.95	0.00
Geray	10491.92	25 Year	274.40	1797.71	1795.50	1795.50	1796.03	0.008798		84.83	80.51	0.00
Geray	10491.92	50 Year	318.40	1797.71	1795.62	1795.62	1796.19	0.008601		95.07	84.21	0.00
Geray	10491.92	100 Year	362.70	1797.71	1795.73	1795.73	1796.35	0.008460		104.54	86.73	0.00
Geray	10332.29	2 Year	109.10	1798.35	1792.67	1792.82	1793.18	0.022796		34.65	69.98	0.00
Geray	10332.29	10 Year	214.90	1798.35	1792.92	1793.18	1793.71	0.026898		54.43	95.73	0.00
Geray	10332.29	25 Year	274.40	1798.35	1793.01	1793.32	1793.94	0.029181		64.37	112.66	0.00
Geray	10332.29	50 Year	318.40	1798.35	1793.07	1793.39	1794.09	0.030812		71.22	122.73	0.00
Geray	10332.29	100 Year	362.70	1798.35	1793.45	1793.45	1793.87	0.009875		126.76	157.75	0.00
Geray	10203.54	2 Year	109.10	1801.64	1798.07	1798.07	1798.33	0.011180		48.21	93.64	0.00
Geray	10203.54	10 Year	214.90	1801.64	1798.39	1798.39	1798.73	0.010084		83.33	123.11	0.00
Geray	10203.54	25 Year	274.40	1801.64	1798.53	1798.53	1798.91	0.009956		100.57	135.25	0.00
Geray	10203.54	50 Year	318.40	1801.64	1798.62	1798.62	1799.02	0.009763		113.27	143.53	0.00
Geray	10203.54	100 Year	362.70	1801.64	1798.70	1798.70	1799.13	0.009573		125.82	151.27	0.00
Geray	10088.76	2 Year	109.10	1804.88	1800.99	1800.99	1801.29	0.010734		44.57	74.62	0.00
Geray	10088.76	10 Year	214.90	1804.88	1801.36	1801.36	1801.76	0.009770		76.78	97.93	0.00
Geray	10088.76	25 Year	274.40	1804.88	1801.52	1801.52	1801.96	0.009505		93.18	107.88	0.00
Geray	10088.76	50 Year	318.40	1804.88	1801.63	1801.63	1802.09	0.009113		105.83	114.97	0.00
Geray	10088.76	100 Year	362.70	1804.88	1801.73	1801.73	1802.22	0.008959		117.44	121.11	0.00
Geray	9856.856	2 Year	109.10	1804.93	1801.86	1801.86	1802.17	0.010705		44.38	73.70	0.00
Geray	9856.856	10 Year	214.90	1804.93	1802.24	1802.24	1802.64	0.009543		76.89	96.64	0.00
Geray	9856.856	25 Year	274.40	1804.93	1802.40	1802.40	1802.84	0.009440		92.69	106.02	0.00
Geray	9856.856	50 Year	318.40	1804.93	1802.51	1802.51	1802.98	0.009136		104.89	112.72	0.00
Geray	9856.856	100 Year	362.70	1804.93	1802.61	1802.61	1803.10	0.008913		116.71	118.85	0.00

Geray	9737.359	2 Year	109.10	1799.20	1797.06	1797.06	1797.36	0.010717		44.91	75.99	0.00
Geray	9737.359	10 Year	214.90	1799.20	1797.44	1797.44	1797.83	0.009611		77.78	100.00	0.00
Geray	9737.359	25 Year	274.40	1799.20	1796.95	1797.59	1799.77	0.114128		36.94	68.92	0.00
Geray	9737.359	50 Year	318.40	1799.20	1797.02	1797.70	1799.98	0.110531		41.80	73.31	0.00
Geray	9737.359	100 Year	362.70	1799.20	1797.09	1797.80	1800.17	0.106909		46.67	77.46	0.00
Geray	9621.062	2 Year	109.10	1801.92	1793.66	1794.01	1794.73	0.032368		23.74	35.30	0.00
Geray	9621.062	10 Year	214.90	1801.92	1794.09	1794.53	1795.46	0.028383		41.47	46.65	0.00
Geray	9621.062	25 Year	274.40	1801.92	1794.64	1794.76	1795.40	0.010857		71.02	60.36	0.00
Geray	9621.062	50 Year	318.40	1801.92	1794.77	1794.91	1795.60	0.010941		79.10	63.58	0.00
Geray	9621.062	100 Year	362.70	1801.92	1794.89	1795.05	1795.78	0.011002		86.98	66.57	0.00
Geray	9465.777	2 Year	109.10	1804.15	1799.75	1799.75	1800.00	0.011197		49.09	98.77	0.00
Geray	9465.777	10 Year	214.90	1804.15	1800.07	1800.07	1800.38	0.009668		87.22	143.57	0.00
Geray	9465.777	25 Year	274.40	1804.15	1800.21	1800.21	1800.54	0.009046		109.12	169.07	0.00
Geray	9465.777	50 Year	318.40	1804.15	1800.30	1800.30	1800.64	0.008828		124.36	184.77	0.00
Geray	9465.777	100 Year	362.70	1804.15	1800.37	1800.37	1800.73	0.008924		137.64	197.42	0.00
Geray	9327.479	2 Year	109.10	1796.58	1793.49	1793.98	1796.31	0.231250		14.68	46.46	0.00
Geray	9327.479	10 Year	214.90	1796.58	1793.71	1794.33	1797.11	0.189310		26.31	62.20	0.00
Geray	9327.479	25 Year	274.40	1796.58	1793.80	1794.48	1797.43	0.174995		32.54	69.19	0.00
Geray	9327.479	50 Year	318.40	1796.58	1793.87	1794.59	1797.60	0.164564		37.23	74.00	0.00
Geray	9327.479	100 Year	362.70	1796.58	1793.93	1794.68	1797.69	0.152676		42.22	78.81	0.00
Geray	9142.432	2 Year	109.10	1796.45	1790.03	1790.06	1790.37	0.011529		42.53	70.04	0.00
Geray	9142.432	10 Year	214.90	1796.45	1790.36	1790.44	1790.86	0.012620		68.35	88.79	0.00
Geray	9142.432	25 Year	274.40	1796.45	1790.50	1790.61	1791.08	0.013069		81.04	96.68	0.00
Geray	9142.432	50 Year	318.40	1796.45	1790.59	1790.72	1791.23	0.013312		89.97	101.87	0.00
Geray	9142.432	100 Year	362.70	1796.45	1790.67	1790.81	1791.36	0.013508		98.66	106.68	0.00
Geray	8958.845	2 Year	109.10	1797.50	1784.47	1784.86	1785.83	0.066001		21.12	45.04	0.00
Geray	8958.845	10 Year	214.90	1797.50	1784.80	1785.27	1786.37	0.052216		38.73	62.21	0.00
Geray	8958.845	25 Year	274.40	1797.50	1784.94	1785.45	1786.60	0.048169		48.06	69.61	0.00
Geray	8958.845	50 Year	318.40	1797.50	1785.03	1785.57	1786.76	0.046076		54.69	74.43	0.00
Geray	8958.845	100 Year	362.70	1797.50	1785.12	1785.67	1786.91	0.044415		61.19	78.87	0.00
Geray	8764.995	2 Year	109.10	1800.34	1781.16	1781.18	1781.50	0.011083		42.72	68.77	0.00
Geray	8764.995	10 Year	214.90	1800.34	1781.49	1781.56	1782.00	0.012426		67.87	86.19	0.00
Geray	8764.995	25 Year	274.40	1800.34	1781.61	1781.72	1782.23	0.012976		78.69	89.34	0.00
Geray	8764.995	50 Year	318.40	1800.34	1781.69	1781.83	1782.39	0.013305		86.20	91.46	0.00
Geray	8764.995	100 Year	362.70	1800.34	1781.77	1781.93	1782.54	0.013547		93.52	93.48	0.00
Geray	8640.239	2 Year	109.10	1798.33	1786.34	1786.34	1786.68	0.010063		42.21	62.07	0.00
Geray	8640.239	10 Year	214.90	1798.33	1786.76	1786.76	1787.21	0.009196		72.33	80.65	0.00
Geray	8640.239	25 Year	274.40	1798.33	1786.96	1786.96	1787.44	0.008499		89.58	94.49	0.00
Geray	8640.239	50 Year	318.40	1798.33	1787.10	1787.10	1787.58	0.007822		104.39	110.24	0.00
Geray	8640.239	100 Year	362.70	1798.33	1787.21	1787.21	1787.70	0.007657		117.36	122.38	0.00
Geray	8411.508	2 Year	109.10	1796.13	1785.61	1785.61	1785.92	0.010601		43.90	71.19	0.00
Geray	8411.508	10 Year	214.90	1796.13	1786.00	1786.00	1786.41	0.009511		75.92	93.39	0.00
Geray	8411.508	25 Year	274.40	1796.13	1786.15	1786.15	1786.62	0.009082		90.83	97.73	0.00
Geray	8411.508	50 Year	318.40	1796.13	1786.26	1786.26	1786.76	0.008881		101.18	100.59	0.00
Geray	8411.508	100 Year	362.70	1796.13	1786.36	1786.36	1786.90	0.008669		111.43	103.34	0.00
Geray	8264.416	2 Year	109.10	1793.22	1786.15	1786.15	1786.49	0.010036		41.77	60.31	0.00
Geray	8264.416	10 Year	214.90	1793.22	1786.56	1786.56	1787.05	0.009038		69.73	72.33	0.00
Geray	8264.416	25 Year	274.40	1793.22	1786.75	1786.75	1787.30	0.008687		83.73	76.74	0.00
Geray	8264.416	50 Year	318.40	1793.22	1786.88	1786.88	1787.47	0.008493		93.68	79.82	0.00
Geray	8264.416	100 Year	362.70	1793.22	1786.99	1786.99	1787.62	0.008473		102.78	82.53	0.00

Geray	8100.701	2 Year	109.10	1787.25	1779.89	1779.89	1780.12	0.011810		51.67	116.10	0.00
Geray	8100.701	10 Year	214.90	1787.25	1780.16	1780.16	1780.48	0.010304		86.25	136.46	0.00
Geray	8100.701	25 Year	274.40	1787.25	1780.27	1780.27	1780.64	0.010026		102.15	141.45	0.00
Geray	8100.701	50 Year	318.40	1787.25	1780.36	1780.36	1780.75	0.009583		114.39	145.17	0.00
Geray	8100.701	100 Year	362.70	1787.25	1780.43	1780.43	1780.86	0.009481		125.18	148.38	0.00
Geray	7937.217	2 Year	109.10	1775.88	1774.94	1775.36	1776.98	0.153027		17.24	50.96	0.00
Geray	7937.217	10 Year	214.90	1775.88	1775.16	1775.66	1777.63	0.144368		30.85	75.61	0.00
Geray	7937.217	25 Year	274.40	1775.88	1775.25	1775.81	1777.86	0.142637		38.39	89.71	0.00
Geray	7937.217	50 Year	318.40	1775.88	1775.30	1775.90	1778.07	0.135004		43.20	92.53	0.00
Geray	7937.217	100 Year	362.70	1775.88	1775.36	1775.99	1778.23	0.123859		48.29	94.22	0.00
Geray	7768.336	2 Year	109.10	1778.10	1774.03	1774.03	1774.40	0.009998		40.67	56.22	0.00
Geray	7768.336	10 Year	214.90	1778.10	1774.48	1774.48	1774.98	0.009055		68.44	69.37	0.00
Geray	7768.336	25 Year	274.40	1778.10	1774.68	1774.68	1775.23	0.008575		83.33	75.48	0.00
Geray	7768.336	50 Year	318.40	1778.10	1774.81	1774.81	1775.40	0.008526		93.04	79.21	0.00
Geray	7768.336	100 Year	362.70	1778.10	1774.93	1774.93	1775.56	0.008351		102.99	82.70	0.00
Geray	7678.089	2 Year	109.10	1778.29	1777.39	1777.39	1777.72	0.010137		42.56	63.67	0.00
Geray	7678.089	10 Year	214.90	1778.29	1777.80	1777.80	1778.24	0.009444		72.67	83.19	0.00
Geray	7678.089	25 Year	274.40	1778.29	1777.98	1777.98	1778.47	0.009098		88.51	91.82	0.00
Geray	7678.089	50 Year	318.40	1778.29	1778.11	1778.11	1778.62	0.008522		101.45	100.92	0.00
Geray	7678.089	100 Year	362.70	1778.29	1778.27	1778.27	1778.74	0.007542		118.52	124.67	0.00
Geray	7522.924	2 Year	109.10	1781.63	1778.57	1778.57	1778.82	0.011464		49.85	103.80	0.00
Geray	7522.924	10 Year	214.90	1781.63	1778.87	1778.87	1779.19	0.010371		86.06	136.38	0.00
Geray	7522.924	25 Year	274.40	1781.63	1779.00	1779.00	1779.35	0.010055		104.58	150.34	0.00
Geray	7522.924	50 Year	318.40	1781.63	1779.09	1779.09	1779.46	0.009768		118.20	159.83	0.00
Geray	7522.924	100 Year	362.70	1781.63	1779.17	1779.17	1779.56	0.009642		130.97	168.24	0.00
Geray	7375.327	2 Year	109.10	1789.24	1779.01	1779.01	1779.33	0.010535		43.82	70.52	0.00
Geray	7375.327	10 Year	214.90	1789.24	1779.39	1779.39	1779.82	0.009464		74.16	87.72	0.00
Geray	7375.327	25 Year	274.40	1789.24	1779.56	1779.56	1780.04	0.009129		89.76	95.36	0.00
Geray	7375.327	50 Year	318.40	1789.24	1779.68	1779.68	1780.19	0.008984		100.64	100.34	0.00
Geray	7375.327	100 Year	362.70	1789.24	1779.79	1779.79	1780.32	0.008669		112.16	105.37	0.00
Geray	7297.35	2 Year	109.10	1793.74	1780.85	1780.85	1781.06	0.012239		54.32	135.45	0.00
Geray	7297.35	10 Year	214.90	1793.74	1781.11	1781.11	1781.37	0.010853		94.23	177.11	0.00
Geray	7297.35	25 Year	274.40	1793.74	1781.21	1781.21	1781.51	0.010720		112.91	190.98	0.00
Geray	7297.35	50 Year	318.40	1793.74	1781.28	1781.28	1781.60	0.010438		126.96	200.79	0.00
Geray	7297.35	100 Year	362.70	1793.74	1781.34	1781.34	1781.69	0.010239		139.93	207.60	0.00
Geray	7191.283	2 Year	109.10	1789.30	1779.43	1779.50	1779.73	0.015532		45.28	122.31	0.00
Geray	7191.283	10 Year	214.90	1789.30	1779.65	1779.76	1780.07	0.016911		74.53	147.89	0.00
Geray	7191.283	25 Year	274.40	1789.30	1779.75	1779.87	1780.22	0.016772		89.96	159.74	0.00
Geray	7191.283	50 Year	318.40	1789.30	1779.81	1779.95	1780.33	0.016960		100.18	167.13	0.00
Geray	7191.283	100 Year	362.70	1789.30	1779.87	1780.02	1780.42	0.017035		110.26	174.11	0.00
Geray	7090.408	2 Year	109.10	1781.26	1772.49	1772.49	1772.70	0.012186		53.86	131.84	0.00
Geray	7090.408	10 Year	214.90	1781.26	1772.73	1772.73	1773.04	0.010653		87.47	144.92	0.00
Geray	7090.408	25 Year	274.40	1781.26	1772.84	1772.84	1773.20	0.010151		104.50	151.12	0.00
Geray	7090.408	50 Year	318.40	1781.26	1772.92	1772.92	1773.30	0.009888		116.42	155.31	0.00
Geray	7090.408	100 Year	362.70	1781.26	1773.00	1773.00	1773.40	0.009629		128.20	159.34	0.00
Geray	6977.341	2 Year	109.10	1765.79	1763.35	1763.96	1768.36	0.474842		11.01	38.80	0.00
Geray	6977.341	10 Year	214.90	1765.79	1763.56	1764.38	1769.26	0.311346		20.32	47.37	0.00
Geray	6977.341	25 Year	274.40	1765.79	1763.67	1764.56	1769.60	0.268667		25.43	51.46	0.00
Geray	6977.341	50 Year	318.40	1765.79	1763.74	1764.68	1769.81	0.245619		29.17	54.27	0.00
Geray	6977.341	100 Year	362.70	1765.79	1763.80	1764.79	1770.00	0.227603		32.89	56.93	0.00

Geray	6908.523	2 Year	109.10	1752.17	1752.87	1753.35	1754.91	0.101493	6.71	17.25	40.56	3.46
Geray	6908.523	10 Year	214.90	1752.17	1753.06	1753.83	1756.75	0.120290	9.36	25.54	46.28	4.01
Geray	6908.523	25 Year	274.40	1752.17	1753.14	1754.05	1757.67	0.125005	10.51	29.63	48.46	4.19
Geray	6908.523	50 Year	318.40	1752.17	1753.20	1754.20	1758.30	0.127378	11.25	32.52	49.94	4.29
Geray	6908.523	100 Year	362.70	1752.17	1753.26	1754.33	1758.90	0.128862	11.91	35.37	51.36	4.37
Geray	6798.923	2 Year	109.10	1746.47	1743.59	1744.19	1746.14	0.108160		15.46	29.84	0.00
Geray	6798.923	10 Year	214.90	1746.47	1743.90	1744.72	1747.46	0.102296		25.72	36.97	0.00
Geray	6798.923	25 Year	274.40	1746.47	1744.03	1744.96	1748.10	0.102501		30.72	39.99	0.00
Geray	6798.923	50 Year	318.40	1746.47	1744.12	1745.11	1748.55	0.103304		34.15	41.93	0.00
Geray	6798.923	100 Year	362.70	1746.47	1744.19	1745.25	1748.98	0.104404		37.42	43.71	0.00
Geray	6648.87	2 Year	109.10	1738.18	1739.52	1739.93	1740.78	0.017884	5.77	25.37	36.06	1.74
Geray	6648.87	10 Year	214.90	1738.18	1739.91	1740.51	1741.79	0.019372	7.34	41.56	45.88	1.90
Geray	6648.87	25 Year	274.40	1738.18	1740.08	1740.76	1742.24	0.020023	8.01	49.62	50.11	1.97
Geray	6648.87	50 Year	318.40	1738.18	1740.19	1740.92	1742.54	0.020476	8.44	55.23	52.86	2.01
Geray	6648.87	100 Year	362.70	1738.18	1740.29	1741.08	1742.83	0.020921	8.85	60.62	55.37	2.05
Geray	6533.062	2 Year	109.10	1747.98	1746.71	1746.71	1746.97	0.011367		48.35	95.54	0.00
Geray	6533.062	10 Year	214.90	1747.98	1747.01	1747.01	1747.39	0.010019		79.35	108.46	0.00
Geray	6533.062	25 Year	274.40	1747.98	1747.16	1747.16	1747.58	0.009383		95.84	114.74	0.00
Geray	6533.062	50 Year	318.40	1747.98	1747.25	1747.25	1747.71	0.009323		106.38	118.58	0.00
Geray	6533.062	100 Year	362.70	1747.98	1747.34	1747.34	1747.83	0.009119		117.29	122.43	0.00
Geray	6408.512	2 Year	109.10	1755.19	1754.66	1754.66	1754.96	0.007743		45.07	76.91	0.00
Geray	6408.512	10 Year	214.90	1755.19	1755.04	1755.04	1755.38	0.007899		82.94	123.97	0.00
Geray	6408.512	25 Year	274.40	1755.19	1755.18	1755.18	1755.55	0.007991		102.20	142.04	0.00
Geray	6408.512	50 Year	318.40	1755.19	1755.28	1755.28	1755.66	0.007918	0.45	116.27	153.92	0.68
Geray	6408.512	100 Year	362.70	1755.19	1755.35	1755.35	1755.76	0.008157	0.68	128.02	163.18	0.76
Geray	6283.494	2 Year	109.10	1763.88	1753.98	1753.98	1754.35	0.010052		40.47	55.79	0.00
Geray	6283.494	10 Year	214.90	1763.88	1754.44	1754.44	1754.92	0.009002		70.03	73.15	0.00
Geray	6283.494	25 Year	274.40	1763.88	1754.63	1754.63	1755.16	0.008789		84.84	80.46	0.00
Geray	6283.494	50 Year	318.40	1763.88	1754.76	1754.76	1755.32	0.008574		95.72	85.42	0.00
Geray	6283.494	100 Year	362.70	1763.88	1754.88	1754.88	1755.47	0.008419		106.25	89.97	0.00
Geray	6135.173	2 Year	109.10	1752.11	1753.58	1753.58	1753.97	0.005036	3.42	46.02	57.67	0.95
Geray	6135.173	10 Year	214.90	1752.11	1754.05	1754.05	1754.59	0.005008	4.17	75.64	68.94	1.00
Geray	6135.173	25 Year	274.40	1752.11	1754.26	1754.26	1754.86	0.004964	4.47	90.79	74.04	1.01
Geray	6135.173	50 Year	318.40	1752.11	1754.40	1754.40	1755.05	0.005011	4.69	100.94	77.27	1.03
Geray	6135.173	100 Year	362.70	1752.11	1754.54	1754.54	1755.22	0.004890	4.84	112.13	80.68	1.02
Geray	6037.721	2 Year	109.10	1761.06	1742.83	1742.83	1743.27	0.009381		36.92	42.02	0.00
Geray	6037.721	10 Year	214.90	1761.06	1743.37	1743.37	1743.97	0.008518		62.69	53.12	0.00
Geray	6037.721	25 Year	274.40	1761.06	1743.61	1743.61	1744.27	0.008229		75.99	58.02	0.00
Geray	6037.721	50 Year	318.40	1761.06	1743.77	1743.77	1744.47	0.008062		85.43	61.26	0.00
Geray	6037.721	100 Year	362.70	1761.06	1743.92	1743.92	1744.66	0.007906		94.74	64.30	0.00
Geray	5951.044	2 Year	109.10	1735.08	1729.72	1730.72	1740.01	0.566797		7.68	17.94	0.00
Geray	5951.044	10 Year	214.90	1735.08	1730.05	1731.30	1740.94	0.385671		14.70	24.66	0.00
Geray	5951.044	25 Year	274.40	1735.08	1730.19	1731.55	1741.33	0.336464		18.57	27.67	0.00
Geray	5951.044	50 Year	318.40	1735.08	1730.29	1731.72	1741.57	0.309707		21.41	29.68	0.00
Geray	5951.044	100 Year	362.70	1735.08	1730.38	1731.87	1741.80	0.288218		24.24	31.57	0.00
Geray	5852.122	2 Year	109.10	1727.08	1726.14	1726.51	1727.34	0.047243		22.47	40.90	0.00
Geray	5852.122	10 Year	214.90	1727.08	1726.42	1726.97	1728.28	0.053702		35.61	51.49	0.00
Geray	5852.122	25 Year	274.40	1727.08	1726.54	1727.16	1728.72	0.056398		42.00	55.92	0.00
Geray	5852.122	50 Year	318.40	1727.08	1726.62	1727.29	1729.02	0.058145		46.42	58.79	0.00
Geray	5852.122	100 Year	362.70	1727.08	1726.69	1727.42	1729.30	0.059706		50.68	61.42	0.00

Geray	5798.696	2 Year	109.10	1725.39	1725.70	1725.79	1726.19	0.013051	1.30	35.40	51.08	1.07
Geray	5798.696	10 Year	214.90	1725.39	1726.03	1726.26	1726.84	0.015965	2.35	54.26	63.23	1.33
Geray	5798.696	25 Year	274.40	1725.39	1726.16	1726.45	1727.15	0.017464	2.87	62.91	67.61	1.45
Geray	5798.696	50 Year	318.40	1725.39	1726.24	1726.58	1727.36	0.018503	3.23	68.72	70.20	1.52
Geray	5798.696	100 Year	362.70	1725.39	1726.32	1726.71	1727.56	0.019490	3.56	74.20	72.56	1.59
Geray	5729.667	2 Year	109.10	1728.03	1728.48	1728.48	1728.72	0.011189	1.56	50.11	104.62	1.05
Geray	5729.667	10 Year	214.90	1728.03	1728.76	1728.76	1729.13	0.009699	2.01	81.06	113.76	1.06
Geray	5729.667	25 Year	274.40	1728.03	1728.90	1728.90	1729.31	0.009231	2.19	96.63	118.09	1.06
Geray	5729.667	50 Year	318.40	1728.03	1728.99	1728.99	1729.44	0.008926	2.31	107.73	121.09	1.06
Geray	5729.667	100 Year	362.70	1728.03	1729.08	1729.08	1729.56	0.008726	2.42	118.30	123.87	1.07
Geray	5537.832	2 Year	109.10	1735.56	1733.58	1733.58	1733.91	0.010300		42.35	63.66	0.00
Geray	5537.832	10 Year	214.90	1735.56	1734.00	1734.00	1734.42	0.009508		75.40	91.74	0.00
Geray	5537.832	25 Year	274.40	1735.56	1734.18	1734.18	1734.63	0.009197		92.47	103.29	0.00
Geray	5537.832	50 Year	318.40	1735.56	1734.29	1734.29	1734.76	0.009099		104.21	110.54	0.00
Geray	5537.832	100 Year	362.70	1735.56	1734.38	1734.38	1734.89	0.009107		115.21	116.93	0.00
Geray	5492.971	2 Year	109.10	1735.89	1731.66	1731.66	1732.01	0.010189		41.80	61.13	0.00
Geray	5492.971	10 Year	214.90	1735.89	1732.08	1732.08	1732.54	0.009381		71.69	80.05	0.00
Geray	5492.971	25 Year	274.40	1735.89	1732.27	1732.27	1732.77	0.008918		87.76	88.57	0.00
Geray	5492.971	50 Year	318.40	1735.89	1732.40	1732.40	1732.92	0.008691		99.07	94.10	0.00
Geray	5492.971	100 Year	362.70	1735.89	1732.50	1732.50	1733.06	0.008633		109.51	98.94	0.00
Geray	5379.669	2 Year	109.10	1736.10	1728.03	1728.53	1730.09	0.107164		17.16	38.55	0.00
Geray	5379.669	10 Year	214.90	1736.10	1728.34	1728.96	1730.79	0.085962		30.99	51.81	0.00
Geray	5379.669	25 Year	274.40	1736.10	1728.47	1729.14	1731.09	0.079866		38.27	57.57	0.00
Geray	5379.669	50 Year	318.40	1736.10	1728.56	1729.27	1731.28	0.075984		43.59	61.45	0.00
Geray	5379.669	100 Year	362.70	1736.10	1728.64	1729.39	1731.44	0.072416		48.94	65.11	0.00
Geray	5279.559	2 Year	109.10	1732.56	1726.16	1726.41	1726.95	0.029572		27.75	48.79	0.00
Geray	5279.559	10 Year	214.90	1732.56	1726.46	1726.85	1727.66	0.033305		44.12	61.52	0.00
Geray	5279.559	25 Year	274.40	1732.56	1726.58	1727.03	1727.99	0.034650		52.22	66.93	0.00
Geray	5279.559	50 Year	318.40	1732.56	1726.66	1727.16	1728.21	0.035433		57.89	70.47	0.00
Geray	5279.559	100 Year	362.70	1732.56	1726.74	1727.28	1728.41	0.036071		63.41	73.75	0.00
Geray	4936.853	2 Year	109.10	1724.25	1721.82	1721.82	1722.07	0.011251		49.66	101.36	0.00
Geray	4936.853	10 Year	214.90	1724.25	1722.11	1722.11	1722.47	0.010113		80.93	114.72	0.00
Geray	4936.853	25 Year	274.40	1724.25	1722.24	1722.24	1722.65	0.009618		97.01	120.48	0.00
Geray	4936.853	50 Year	318.40	1724.25	1722.34	1722.34	1722.78	0.009387		108.20	124.33	0.00
Geray	4936.853	100 Year	362.70	1724.25	1722.42	1722.42	1722.90	0.009204		119.05	127.95	0.00
Geray	4863.901	2 Year	109.10	1719.72	1718.65	1719.01	1720.13	0.118344		20.20	62.45	0.00
Geray	4863.901	10 Year	214.90	1719.72	1718.86	1719.31	1720.71	0.100997		35.64	82.96	0.00
Geray	4863.901	25 Year	274.40	1719.72	1718.95	1719.44	1720.97	0.095889		43.65	91.81	0.00
Geray	4863.901	50 Year	318.40	1719.72	1719.01	1719.53	1721.12	0.092440		49.48	97.75	0.00
Geray	4863.901	100 Year	362.70	1719.72	1719.07	1719.61	1721.27	0.089629		55.19	103.24	0.00
Geray	4758.956	2 Year	109.10	1716.51	1717.31	1717.34	1717.67	0.009514	3.27	42.85	69.24	1.19
Geray	4758.956	10 Year	214.90	1716.51	1717.65	1717.74	1718.21	0.009879	4.25	68.74	83.70	1.29
Geray	4758.956	25 Year	274.40	1716.51	1717.80	1717.92	1718.44	0.009975	4.65	81.83	90.14	1.32
Geray	4758.956	50 Year	318.40	1716.51	1717.90	1718.04	1718.60	0.010008	4.90	91.13	94.45	1.34
Geray	4758.956	100 Year	362.70	1716.51	1717.99	1718.15	1718.75	0.010028	5.13	100.21	98.46	1.36
Geray	4695.626	2 Year	109.10	1720.34	1717.67	1717.67	1717.92	0.011487		49.66	102.96	0.00
Geray	4695.626	10 Year	214.90	1720.34	1717.96	1717.96	1718.32	0.010064		81.21	115.31	0.00
Geray	4695.626	25 Year	274.40	1720.34	1718.09	1718.09	1718.50	0.009663		97.05	121.04	0.00
Geray	4695.626	50 Year	318.40	1720.34	1718.19	1718.19	1718.63	0.009297		108.77	125.10	0.00
Geray	4695.626	100 Year	362.70	1720.34	1718.27	1718.27	1718.74	0.009154		119.52	128.72	0.00

Geray	4536.364	2 Year	109.10	1717.95	1718.28	1718.28	1718.47	0.011364	1.99	57.03	150.15	1.13
Geray	4536.364	10 Year	214.90	1717.95	1718.50	1718.50	1718.79	0.010122	2.67	91.25	159.59	1.16
Geray	4536.364	25 Year	274.40	1717.95	1718.61	1718.61	1718.94	0.009759	2.95	108.09	164.03	1.17
Geray	4536.364	50 Year	318.40	1717.95	1718.68	1718.68	1719.04	0.009469	3.12	120.19	167.16	1.18
Geray	4536.364	100 Year	362.70	1717.95	1718.75	1718.75	1719.14	0.009198	3.27	132.06	170.16	1.18
Geray	4409.693	2 Year	109.10	1718.76	1718.96	1718.96	1719.11	0.011780	1.41	62.95	200.59	1.05
Geray	4409.693	10 Year	214.90	1718.76	1719.13	1719.13	1719.38	0.010731	2.11	99.52	208.24	1.12
Geray	4409.693	25 Year	274.40	1718.76	1719.22	1719.22	1719.50	0.010057	2.37	118.54	212.11	1.12
Geray	4409.693	50 Year	318.40	1718.76	1719.28	1719.28	1719.59	0.009962	2.55	130.63	214.53	1.14
Geray	4409.693	100 Year	362.70	1718.76	1719.34	1719.34	1719.67	0.009632	2.70	143.42	217.06	1.14
Geray	4337.544	2 Year	109.10	1719.29	1719.50	1719.50	1719.65	0.010866	1.41	67.46	235.78	1.02
Geray	4337.544	10 Year	214.90	1719.29	1719.67	1719.67	1719.88	0.010132	2.04	106.46	241.12	1.08
Geray	4337.544	25 Year	274.40	1719.29	1719.74	1719.74	1720.00	0.009930	2.30	124.97	243.61	1.11
Geray	4337.544	50 Year	318.40	1719.29	1719.79	1719.79	1720.08	0.009859	2.46	137.52	245.29	1.13
Geray	4337.544	100 Year	362.70	1719.29	1719.85	1719.85	1720.15	0.009460	2.59	151.18	247.10	1.12
Geray	4126.341	2 Year	109.10	1718.08	1718.64	1718.64	1718.85	0.009235	2.53	58.43	149.82	1.11
Geray	4126.341	10 Year	214.90	1718.08	1718.89	1718.89	1719.16	0.008191	3.07	100.34	189.85	1.11
Geray	4126.341	25 Year	274.40	1718.08	1719.00	1719.00	1719.30	0.007964	3.29	121.55	207.19	1.12
Geray	4126.341	50 Year	318.40	1718.08	1719.08	1719.08	1719.39	0.007235	3.34	140.26	218.66	1.08
Geray	4126.341	100 Year	362.70	1718.08	1719.14	1719.14	1719.47	0.007339	3.50	152.86	223.26	1.10
Geray	4007.683	2 Year	109.10	1717.16	1717.73	1717.73	1717.94	0.009276	2.52	56.98	138.18	1.11
Geray	4007.683	10 Year	214.90	1717.16	1717.95	1717.98	1718.27	0.009999	3.31	90.82	164.14	1.22
Geray	4007.683	25 Year	274.40	1717.16	1718.05	1718.09	1718.42	0.010301	3.64	107.34	175.44	1.26
Geray	4007.683	50 Year	318.40	1717.16	1718.10	1718.17	1718.52	0.011046	3.92	116.64	181.48	1.32
Geray	4007.683	100 Year	362.70	1717.16	1718.17	1718.24	1718.61	0.010810	4.07	129.31	189.40	1.32
Geray	3700.823	2 Year	109.10	1725.71	1717.38	1717.38	1717.63	0.011582		49.81	104.40	0.00
Geray	3700.823	10 Year	214.90	1725.71	1717.68	1717.68	1718.01	0.010290		84.23	128.47	0.00
Geray	3700.823	25 Year	274.40	1725.71	1717.81	1717.81	1718.18	0.009815		102.21	139.40	0.00
Geray	3700.823	50 Year	318.40	1725.71	1717.90	1717.90	1718.29	0.009612		114.72	146.52	0.00
Geray	3700.823	100 Year	362.70	1725.71	1717.98	1717.98	1718.40	0.009405		127.12	153.26	0.00
Geray	3652.102	2 Year	109.10	1727.27	1717.75	1717.75	1717.99	0.011682		50.38	108.10	0.00
Geray	3652.102	10 Year	214.90	1727.27	1718.05	1718.05	1718.36	0.010453		87.34	142.33	0.00
Geray	3652.102	25 Year	274.40	1727.27	1718.17	1718.17	1718.51	0.010321		105.41	156.36	0.00
Geray	3652.102	50 Year	318.40	1727.27	1718.25	1718.25	1718.62	0.010042		119.06	166.18	0.00
Geray	3652.102	100 Year	362.70	1727.27	1718.33	1718.33	1718.71	0.009858		132.19	175.11	0.00
Geray	3406.556	2 Year	109.10	1720.13	1718.68	1718.68	1718.90	0.011616		51.87	115.78	0.00
Geray	3406.556	10 Year	214.90	1720.13	1718.95	1718.95	1719.27	0.010447		85.44	134.66	0.00
Geray	3406.556	25 Year	274.40	1720.13	1719.07	1719.07	1719.43	0.009872		103.27	143.68	0.00
Geray	3406.556	50 Year	318.40	1720.13	1719.16	1719.16	1719.55	0.009679		115.40	149.51	0.00
Geray	3406.556	100 Year	362.70	1720.13	1719.23	1719.23	1719.65	0.009592		126.88	154.82	0.00
Geray	3311.333	2 Year	109.10	1717.17	1717.32	1717.40	1717.61	0.022050	1.31	46.23	152.69	1.30
Geray	3311.333	10 Year	214.90	1717.17	1717.47	1717.60	1717.95	0.026264	2.57	71.30	189.12	1.64
Geray	3311.333	25 Year	274.40	1717.17	1717.52	1717.69	1718.12	0.028034	3.04	81.88	191.59	1.75
Geray	3311.333	50 Year	318.40	1717.17	1717.56	1717.76	1718.23	0.028499	3.33	89.66	192.95	1.81
Geray	3311.333	100 Year	362.70	1717.17	1717.60	1717.82	1718.34	0.028521	3.58	97.47	194.31	1.84
Geray	3156.893	2 Year	109.10	1721.44	1715.75	1715.75	1715.95	0.012085		54.78	136.69	0.00
Geray	3156.893	10 Year	214.90	1721.44	1716.00	1716.00	1716.27	0.010886		93.52	174.08	0.00
Geray	3156.893	25 Year	274.40	1721.44	1716.11	1716.11	1716.41	0.010694		112.72	189.91	0.00
Geray	3156.893	50 Year	318.40	1721.44	1716.18	1716.18	1716.50	0.010283		127.66	201.36	0.00
Geray	3156.893	100 Year	362.70	1721.44	1716.24	1716.24	1716.58	0.010285		140.57	210.76	0.00

Geray	3009.401	2 Year	109.10	1719.66	1716.31	1716.31	1716.46	0.013497		62.07	202.99	0.00
Geray	3009.401	10 Year	214.90	1719.66	1716.49	1716.49	1716.72	0.011498		101.31	221.61	0.00
Geray	3009.401	25 Year	274.40	1719.66	1716.58	1716.58	1716.84	0.011183		120.07	229.98	0.00
Geray	3009.401	50 Year	318.40	1719.66	1716.63	1716.63	1716.92	0.010876		133.72	235.89	0.00
Geray	3009.401	100 Year	362.70	1719.66	1716.69	1716.69	1717.00	0.010496		147.59	241.74	0.00
Geray	2811.414	2 Year	109.10	1718.69	1717.46	1717.46	1717.69	0.011464		50.54	107.40	0.00
Geray	2811.414	10 Year	214.90	1718.69	1717.75	1717.75	1718.07	0.010437		85.84	136.18	0.00
Geray	2811.414	25 Year	274.40	1718.69	1717.87	1717.87	1718.23	0.010106		104.00	148.82	0.00
Geray	2811.414	50 Year	318.40	1718.69	1717.96	1717.96	1718.34	0.009925		116.84	157.15	0.00
Geray	2811.414	100 Year	362.70	1718.69	1718.04	1718.04	1718.44	0.009593		130.28	165.43	0.00
Geray	2487.493	2 Year	109.10	1715.68	1714.79	1714.90	1715.23	0.019904		36.97	74.35	0.00
Geray	2487.493	10 Year	214.90	1715.68	1715.07	1715.25	1715.70	0.020283		61.04	95.53	0.00
Geray	2487.493	25 Year	274.40	1715.68	1715.19	1715.40	1715.90	0.020228		73.40	104.75	0.00
Geray	2487.493	50 Year	318.40	1715.68	1715.27	1715.50	1716.04	0.020164		82.15	110.82	0.00
Geray	2487.493	100 Year	362.70	1715.68	1715.34	1715.59	1716.17	0.020399		90.19	116.12	0.00
Geray	2363.27	2 Year	109.10	1709.47	1709.76	1710.11	1711.02	0.055710	2.62	22.62	54.40	2.19
Geray	2363.27	10 Year	214.90	1709.47	1710.02	1710.48	1711.66	0.048220	4.74	38.89	69.99	2.40
Geray	2363.27	25 Year	274.40	1709.47	1710.14	1710.65	1711.95	0.045766	5.47	47.17	73.78	2.44
Geray	2363.27	50 Year	318.40	1709.47	1710.22	1710.77	1712.15	0.044238	5.92	53.03	76.35	2.46
Geray	2363.27	100 Year	362.70	1709.47	1710.29	1710.88	1712.32	0.042415	6.29	59.00	78.88	2.46
Geray	2184.716	2 Year	109.10	1718.57	1710.18	1710.18	1710.53	0.010158		41.60	60.23	0.00
Geray	2184.716	10 Year	214.90	1718.57	1710.62	1710.62	1711.07	0.009138		71.96	79.23	0.00
Geray	2184.716	25 Year	274.40	1718.57	1710.80	1710.80	1711.31	0.009010		86.90	87.06	0.00
Geray	2184.716	50 Year	318.40	1718.57	1710.92	1710.92	1711.46	0.008750		97.93	91.88	0.00
Geray	2184.716	100 Year	362.70	1718.57	1711.03	1711.03	1711.60	0.008582		108.37	95.95	0.00
Geray	2036.622	2 Year	109.10	1722.96	1714.93	1714.93	1715.26	0.010344		43.00	66.39	0.00
Geray	2036.622	10 Year	214.90	1722.96	1715.33	1715.33	1715.77	0.009367		73.02	83.76	0.00
Geray	2036.622	25 Year	274.40	1722.96	1715.51	1715.51	1716.00	0.008934		88.91	91.63	0.00
Geray	2036.622	50 Year	318.40	1722.96	1715.63	1715.63	1716.15	0.008764		99.89	96.69	0.00
Geray	2036.622	100 Year	362.70	1722.96	1715.73	1715.73	1716.29	0.008723		110.16	101.20	0.00
Geray	1902.089	2 Year	109.10	1719.45	1714.84	1714.84	1715.13	0.010684		45.36	77.74	0.00
Geray	1902.089	10 Year	214.90	1719.45	1715.20	1715.20	1715.59	0.009686		76.96	97.97	0.00
Geray	1902.089	25 Year	274.40	1719.45	1715.36	1715.36	1715.80	0.009358		93.25	106.90	0.00
Geray	1902.089	50 Year	318.40	1719.45	1715.46	1715.46	1715.93	0.009178		104.77	112.80	0.00
Geray	1902.089	100 Year	362.70	1719.45	1715.56	1715.56	1716.06	0.009008		116.12	118.33	0.00
Geray	1736.239	2 Year	109.10	1719.55	1715.02	1715.02	1715.33	0.010561		44.13	71.93	0.00
Geray	1736.239	10 Year	214.90	1719.55	1715.40	1715.40	1715.81	0.009630		75.63	93.35	0.00
Geray	1736.239	25 Year	274.40	1719.55	1715.57	1715.57	1716.02	0.009317		91.87	102.66	0.00
Geray	1736.239	50 Year	318.40	1719.55	1715.68	1715.68	1716.16	0.009130		103.44	108.81	0.00
Geray	1736.239	100 Year	362.70	1719.55	1715.78	1715.78	1716.29	0.008985		114.69	114.47	0.00
Geray	1530.658	2 Year	109.10	1716.84	1715.20	1715.20	1715.51	0.010764		44.51	74.54	0.00
Geray	1530.658	10 Year	214.90	1716.84	1715.58	1715.58	1715.97	0.009607		77.24	98.23	0.00
Geray	1530.658	25 Year	274.40	1716.84	1715.73	1715.73	1716.17	0.009430		93.43	108.04	0.00
Geray	1530.658	50 Year	318.40	1716.84	1715.84	1715.84	1716.31	0.009310		104.96	114.52	0.00
Geray	1530.658	100 Year	362.70	1716.84	1715.94	1715.94	1716.43	0.009019		117.12	120.98	0.00
Geray	1414.201	2 Year	109.10	1720.10	1714.79	1714.79	1715.10	0.010383		44.13	71.03	0.00
Geray	1414.201	10 Year	214.90	1720.10	1715.18	1715.18	1715.59	0.009481		75.93	93.16	0.00
Geray	1414.201	25 Year	274.40	1720.10	1715.34	1715.34	1715.80	0.009261		92.01	102.56	0.00
Geray	1414.201	50 Year	318.40	1720.10	1715.46	1715.46	1715.94	0.008997		103.99	109.03	0.00
Geray	1414.201	100 Year	362.70	1720.10	1715.56	1715.56	1716.06	0.008837		115.43	114.87	0.00

Geray	1240.36	2 Year	109.10	1717.39	1714.03	1714.03	1714.26	0.011556		51.33	112.34	0.00
Geray	1240.36	10 Year	214.90	1717.39	1714.32	1714.32	1714.62	0.010489		88.68	148.22	0.00
Geray	1240.36	25 Year	274.40	1717.39	1714.43	1714.43	1714.77	0.010434		106.78	162.79	0.00
Geray	1240.36	50 Year	318.40	1717.39	1714.52	1714.52	1714.87	0.010144		120.68	173.15	0.00
Geray	1240.36	100 Year	362.70	1717.39	1714.60	1714.60	1714.97	0.009782		134.91	183.16	0.00
Geray	1092.189	2 Year	109.10	1718.13	1713.02	1713.02	1713.25	0.011478		51.32	111.72	0.00
Geray	1092.189	10 Year	214.90	1718.13	1713.29	1713.29	1713.63	0.010307		83.06	124.23	0.00
Geray	1092.189	25 Year	274.40	1718.13	1713.41	1713.41	1713.80	0.009867		99.29	130.16	0.00
Geray	1092.189	50 Year	318.40	1718.13	1713.50	1713.50	1713.92	0.009576		110.90	134.24	0.00
Geray	1092.189	100 Year	362.70	1718.13	1713.59	1713.59	1714.04	0.009359		122.10	138.07	0.00
Geray	959.0341	2 Year	109.10	1709.91	1710.94	1711.14	1711.60	0.016189	4.40	32.19	52.74	1.57
Geray	959.0341	10 Year	214.90	1709.91	1711.35	1711.60	1712.20	0.013561	5.31	57.60	70.52	1.54
Geray	959.0341	25 Year	274.40	1709.91	1711.54	1711.80	1712.44	0.012668	5.63	71.23	78.42	1.52
Geray	959.0341	50 Year	318.40	1709.91	1711.66	1711.93	1712.61	0.012192	5.84	80.97	83.61	1.51
Geray	959.0341	100 Year	362.70	1709.91	1711.77	1712.06	1712.76	0.011759	6.01	90.69	88.48	1.50
Geray	789.027	2 Year	109.10	1710.40	1703.55	1703.55	1703.91	0.009876		40.96	56.74	0.00
Geray	789.027	10 Year	214.90	1710.40	1703.99	1703.99	1704.49	0.008896		68.84	69.45	0.00
Geray	789.027	25 Year	274.40	1710.40	1704.19	1704.19	1704.75	0.008578		83.17	75.15	0.00
Geray	789.027	50 Year	318.40	1710.40	1704.32	1704.32	1704.92	0.008405		93.30	78.93	0.00
Geray	789.027	100 Year	362.70	1710.40	1704.45	1704.45	1705.08	0.008246		103.27	82.49	0.00
Geray	563.6366	2 Year	109.10	1707.00	1706.16	1706.16	1706.48	0.010320		43.80	69.37	0.00
Geray	563.6366	10 Year	214.90	1707.00	1706.55	1706.55	1706.97	0.009498		75.14	90.85	0.00
Geray	563.6366	25 Year	274.40	1707.00	1706.72	1706.72	1707.18	0.009191		91.37	100.18	0.00
Geray	563.6366	50 Year	318.40	1707.00	1706.84	1706.84	1707.32	0.008945		103.20	106.47	0.00
Geray	563.6366	100 Year	362.70	1707.00	1706.94	1706.94	1707.45	0.008910		113.95	111.88	0.00
Geray	454.253	2 Year	109.10	1710.59	1709.40	1709.40	1709.66	0.011123		47.80	91.35	0.00
Geray	454.253	10 Year	214.90	1710.59	1709.72	1709.72	1710.07	0.010217		82.05	119.68	0.00
Geray	454.253	25 Year	274.40	1710.59	1709.86	1709.86	1710.25	0.009937		99.59	131.85	0.00
Geray	454.253	50 Year	318.40	1710.59	1709.96	1709.96	1710.36	0.009519		113.04	140.21	0.00
Geray	454.253	100 Year	362.70	1710.59	1710.04	1710.04	1710.47	0.009486		124.52	146.47	0.00
Geray	340.364	2 Year	109.10	1712.17	1706.27	1706.27	1706.49	0.011915		52.58	122.06	0.00
Geray	340.364	10 Year	214.90	1712.17	1706.54	1706.54	1706.84	0.010526		87.39	143.30	0.00
Geray	340.364	25 Year	274.40	1712.17	1706.65	1706.65	1707.00	0.010187		104.87	152.85	0.00
Geray	340.364	50 Year	318.40	1712.17	1706.74	1706.74	1707.11	0.009869		117.74	159.52	0.00
Geray	340.364	100 Year	362.70	1712.17	1706.81	1706.81	1707.21	0.009666		130.06	165.65	0.00
Geray	274.3892	2 Year	109.10	1711.99	1703.50	1703.79	1704.58	0.098283		23.73	81.31	0.00
Geray	274.3892	10 Year	214.90	1711.99	1703.69	1704.06	1705.13	0.083643		40.39	98.47	0.00
Geray	274.3892	25 Year	274.40	1711.99	1703.78	1704.19	1705.35	0.077576		49.37	106.58	0.00
Geray	274.3892	50 Year	318.40	1711.99	1703.83	1704.27	1705.50	0.074611		55.70	111.94	0.00
Geray	274.3892	100 Year	362.70	1711.99	1703.89	1704.35	1705.63	0.071752		62.04	117.07	0.00
Geray	214.9851	2 Year	109.10	1711.76	1705.04	1705.04	1705.28	0.011378		50.01	103.28	0.00
Geray	214.9851	10 Year	214.90	1711.76	1705.32	1705.32	1705.69	0.009926		80.21	109.60	0.00
Geray	214.9851	25 Year	274.40	1711.76	1705.45	1705.45	1705.88	0.009597		94.85	112.53	0.00
Geray	214.9851	50 Year	318.40	1711.76	1705.55	1705.55	1706.01	0.009227		105.76	114.67	0.00
Geray	214.9851	100 Year	362.70	1711.76	1705.64	1705.64	1706.14	0.008995		116.05	116.65	0.00